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INTERPRETATION OF SATELLITE IMAGES OF THE REPUBLIC OF NIGER.
FINAL REPORT

F. Bender and D. Bannert

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16. Abstract Interpretations of Landsat pictures were carried out for an area located in the west of the Niger Republic in the geological, hydrogeological and pedological sectors. Checking of the extent of vegetation, use of the soils and effects of desertification for the purpose of yearly map-making was carried out. The proposed control of land use may be optimized by the direct reception of LANDSAT data by the receiving station planned for Ouagadougou. Since that station will not be operating before 1983, there is advised the establishment of a mobile reception station in the Republic of Niger to enable the installation of the required control system.			
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INTERPRETATION OF SATELLITE IMAGES OF THE REPUBLIC OF NIGER
FINAL REPORT

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INTERPRETATION OF SATELLITE IMAGES OF THE REPUBLIC OF NIGER.
FINAL REPORT

F. Bender and D. Bannert

1. Summary

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Within the framework of the technical cooperation with the Republic of Niger, the Federal Office of Geological Sciences and Mines, Hanover, Federal Republic of Germany, pursued from 1975 to 1978 investigations relating to the project: "Interpretation of Satellite Pictures: Documentation for a Project of Long-Term Assistance to the Sahel."

Within the framework of this project, the interpretations of LANDSAT satellite pictures were carried out in the geological, hydrogeological and pedological sectors. Investigations on the terrain were added to the program to verify the results. The investigations were also aimed at identifying the regions of dry farming according to the satellite pictures.

During the operations carried out for this project, a system was developed which permits the control of the extent of the vegetation, the use of the soils and the effects of desertification to make it possible to establish every year maps of use over fairly extensive areas, by means of data furnished by Earth Research satellites and revised by electronic data processing.

We have been supported in our work by the concerned administrations and organizations of the Republic of Niger, whom we wish to thank here, in particular:

- the Ministry of Mines and Hydrology
- the Ministry of Rural Development
- the Niger National Institute of Agronomic Research
- the Niger Office of Underground Waters
- the Program of Reconstitution of the Cheptel and Centers of Multiplications
- the Department of Rural Engineering
- the Services of Climatology, Meteorology and
- the Embassy of the Federal Republic of Germany

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The region chosen for the study is an area located in the west of the Niger Republic. It has the following coordinates: 16°N to 13°N and 01°E to 06°E.

All the photographs obtained between 1972 and 1976 by the LANDSAT system, which could be made available to us were used: indeed we were able to observe that many phenomena connected with

*Numbers in the margin indicate pagination in the foreign text.

vegetation changes could only be identified by changes in the pictures taken in different seasons. We used color and black and white pictures furnished by the different LANDSAT channels.

The geological interpretation did not add anything important to the existing maps. But it was possible to observe many photo-lineations not indicated in the documents known to us, and which are certainly significant for the prospection of underground waters, especially in the Liptako regions. Furthermore it was possible to reveal the possible reserves of underground waters in the stationary dunes, which would be important for supplying with water the cultivated areas. On the whole, we were able to observe possibilities of obtaining water near 20 villages of Liptako.

During the pedological interpretation, it became apparent, as was expected, that it was impossible to determine the type of soil from satellite pictures, and it was absolutely necessary to carry out verification on the terrain. But we were able to draw conclusions on the typological criteria of the soil, for instance, for laterite crust soils or hydromorphous soils, from the pedological characteristics visible on the satellite picture, or which could be visualized by electronic data processing. The interpretation of the pictures may be falsified by the presence of a loose soil cover; such errors are prevented by verification on the terrain. Generally speaking, we were able to observe that the associations of soils within physiographic units were those which could be identified with greatest certainty: the scale is suitable, but also the relative clearness with which the physiographic units appear on the satellite picture. /3

Dynamic phenomena, such as erosion, formation of channels, the extension of irrigated or planted areas and to a certain extent the extension of the ponds, may be identified on satellite pictures when they occur over large areas, by comparing repeated photographs. Morphological elements, such as rivers, valleys, embankments, the relief and the plains can be recognized clearly on satellite pictures. They are also used to determine the pedological units, since the latter may be derived from the correlation established between the morphological characteristics and the use of the soils.

The map of the soils shows the units which we distinguished. In the legends, we indicate for each pedological unit, its possible use derived from its suitability as soil for dry farming and irrigated cultivation or as pasture land. Besides a general more intensive use of the soils of the Niger Republic, we recognize on the satellite picture certain regions which may be specific for specific use. These are in particular hydromorphous soils for planting vegetables in the furrows of the dallols in the southern area of our sector. Investigations should therefore be pursued to implement such a project. /4

It is easy to identify on the pictures the large valleys such as may be found in the north of Karma and Gotheye. Marly soils, with sandy sesquioxides, represent a good subsoil for

intensive dry farming. Detailed studies should permit the precise identification of the given situation.

Within the area of the alluvial deposits of the Niger, two potential regions may be distinguished for cultivation in irrigated conditions: the area located around Koulou, northwest of Gaya; there is already a pedological map on the 1:10,000 scale by Dabin & Perraud. In the alluvial deposits located northwest of Gotheye, we may identify other humid sectors whose precise survey shows a certain possibility for organizing there irrigated cultivation.

In the North, on the banks of the Tahoua region, we may demarcate on the satellite picture regions which may be used for fodder reserves, because of the changes in the vegetation in the course of the seasons. This suggests to us the coordination of pastures in the threatened regions.

We chose the sector studied in view of its ecological instability determined by annual rainfalls between 200 and 500 mm. Actually this region is particularly exposed to agricultural over-use. Except for the irrigated sectors, the agriculturally used regions are used both for dry farming and cattle raising. The areas used for dry farming are especially fragile under erosion, which has led in many cases to the total destruction of the soils. The destruction of the natural vegetation which represents the basic living of nomad cattle breeders is therefore not limited only to the dry farming areas, but overpasturing has assumed critical proportions even near the wells. We therefore established a map of land use according to the satellite pictures, which indicates the areas affected particularly, and in which the vegetation has already suffered considerable degradation. We have also indicated the sectors in which dry farming is now only practised sporadically. /5

These investigations represent the basis of an automatic system of control of the areas threatened by desertification, capable of detecting the sectors in which vegetation has disappeared as a result of desertification, and of following their progress in the course of time. To be able to apply practically the automatized survey of maps of land use, we developed a map survey method by electronic data processing.

This process makes it possible to produce in a few operations models for printing land use maps from crude LANDSAT data recorded on magnetic tapes. We therefore established by this means the principles which would make it possible to obtain according to request, at short time intervals or annually, land use maps indicating the extent of desertification and making it possible, besides this problem, to control continuously the progress achieved in the area of use of the land. This problem of control has been considered very important for the past few years. It is always referred to by the organizations dealing with the problem of desertification, in particular by the "United Nations' Conference on Desertification" in Nairobi, 1977. /6

The control of the use of lands which we propose may be optimized by direct reception of LANDSAT data to the receiving station foreseen in Ouagadougou. Seeing that this station will not be operating before 1983, we advise setting up in the Republic of Niger a mobile reception station to enable the installation of the required control system.

2. Introduction

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According to the data of the United Nations, presented in Nairobi in 1977 during the "United Nations' Conference on Desertification", 600 million persons (14% of the current world population) live in regions threatened by the spread of the deserts. Of these 600 millions, 50 to 80 million are now exposed to real danger because of the regression of rural production caused by phenomena of desertification. In the region of South Sahara alone, 650,000 km² have been converted into desert areas in the last 5 years.

These problems led the Ministry of Economic Cooperation to turn to remote detection by research satellite, to attempt to approach the problems of the Sahel with the technological advances achieved in this sector.

The draft of a project was established in 1973 in cooperation with the BGR (Federal Office of Geological Sciences and Minerals); it was provided that an attempt would be made to establish basic data on the basis of the interpretation of satellite observations to use them as far as possible in the struggle against desertification. It was then clearly apparent that one of the major problems was in the determination of the present ecological condition on the basis of the survey of the situation in the countries concerned. One of the other important problems is the control of this situation in the next few decades to know whether the technical and organizational measures which were taken against the development of desertification have had positive effects.

The Federal Ministry of Economic Cooperation assigned by a decree of 7 October 1974, to the BGR the implementation of the project "Interpretation of Satellite Pictures: Documentation for a Program of Assistance to the Sahel." The region chosen for the studies is located in the west of the Niger Republic. The coordinates are as follows: 13-16°N and 1-6°E (Fig. 1).

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The project was presented to the Nigerian Ministry. It was studied with interest by the National Institute of Agronomic Research of the Niger and the Hydrology Department. These organizations have supported us by placing at our disposal the statistical documents which we needed and by introducing us to the administrations of the provinces of the regions in which we operated.

Within the framework of our project, our purpose was to define the extent of the soils suitable for cultivation and the reserves

of underground waters, the development of precipitations and the use of the lands of a certain portion of the Niger Republic. The work began in June 1975 with the choice and rectification of the satellite material, to be followed by the actual interpretation in April, 1976. We applied ourselves to carrying out an interdisciplinary study of the pictures supplied by the NASA LANDSAT Research Satellite system (formerly known as ERTS), completing this with researches on sociology and the development of the climate of the last few years.

We had foreseen the cooperation of the Bochum Observatory and the Deutsches Hydrographisches Institut (German Hydrographic Institute), also a sociologist, besides the BGR and the Geographic Institute of the Hamburg University. But during the project it was observed that it was impossible to engage a sociologist within the framework provided. Technical reasons prevented the interpretation of meteorological series of satellite pictures.

The members of the working group covered the sector of work both in the dry and rainy seasons. On the whole, the work on the site required 4 man months for pedology, 3 man months for hydrogeology and 4 man months for geography. /9

Pedological maps have been established under the aspect of the potential of use of the lands, hydrogeological maps with new proposals for water supply in rural sectors and general maps with the extent of dry farming areas, while all these documents will be used as basis for the control system proposed in the struggle against soil degradation.

Thus we created within the framework of the project conditions permitting the annual establishment of series of maps over large areas to evaluate and control the development of desertification. The creation of this control system had been another major element of the previous year's "United Nations' Conference on Desertification."

2.1. Initial Situation

The Sahel countries are dominated by an extremely unstable ecological balance which may be influenced by many factors. Among them, we may mention the increase of the population and the poor crops.

In the last few years, the increase of the population led to the use of lands located increasingly to the north, towards a region of dry savanna for traditional nomad cattle breeding. The savanna was therefore cleared and dry farming was started. The animal breeders have been driven back, and their domain was thus reduced. A slight compensation was provided by the installation of new deeper wells of greater flow, whose consequence was an increase in the number of animals per herd without there being sufficient fodder to feed them. /10

During the great catastrophic drought of the seventies, the ecological balance, which had already been greatly disturbed, was totally destroyed. The dry farming areas supplied only poor crops and the herds of the nomads found no food. The winds of the dry seasons eroded the cultivated regions, and large areas were subsequently no longer suitable for use. The lack of rainfall dried up the shallow wells, and men and animals were threatened by lack of water.

It was under the effect of these elements that the project was conceived. The purpose of the geological and pedological surveys was to supply basic data for an organization making it possible to give assistance to the country. These data were then used to furnish basic data for setting up new points for seeking underground water in the particularly threatened regions and to develop an annual control system for the identification of the dynamic factors in the part of the Niger Republic affected by desertification.

2.1.1. Documents Used

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The cartography of the Niger Republic is very irregular. There are topographic documents of large areas on the scales 1:200,000, 1:500,000 and 1:1 million.

As regards pedology, we may mention the "Soil Map of Africa" by Hoore (1964) on the scale 1:5,000,000 and the maps "Soil Map of the World", scale 1:5,000,000 (FAO/UNESCO, 1972, 1973). These maps provide good general views of associations of soils and they are important for correlation studies. On a larger scale (1:500,000 and 1:100,000), ORSTOM established pedological maps (Gavaud and Boulet, page on Maradi and Niamey 1964, 1967; Bocquier and Gavaud, page on Zinder and Ader Doutch, undated) allowing direct comparison with satellite pictures. But these maps include only the southern part of the country up to 15°N latitude. They are supplemented by very complete descriptions of the soils (no. 6500/200, 1964; 6500/129, 1964; 6500/311, 1967). Large scale detailed surveys have been established by different companies and were available to us in the form of local reports (SOGETHA, 1962, 1963, 1965; SOGREAH, 1969, 1975, 1977; Hunting, 1970).

The following studies were used for the pedological interpretation: Aubert 1964, Beaudet et al., 1977; Didier de Saint-Amand, 1969, etc. There is no cartographic representation of the use of land over the whole of the Republic of Niger, but there is a transparent sheet on the Zinder document (Bocquier and Gavaud on the scale 1:500,000) showing the current use of the land. The areas further to the west are not processed. In certain studies, we also find indications on the use of land, which concern however only small sectors.

For the geological interpretation, we used the "Geological Map of the Niger Republic, 1967" on the scale 1:2,000,000 by Greigert, /12

J. and Pougnet, R. We have also access to the "Geological Prospection Map of the Iullemeden basin", 1:1,000,000 by Greigert. Finally for the Niamey region, we used the "Geological Map of the Western Niger," pages 1 and 2 by E. Machens of 1966.

2.1.2. Climate

The area covered by the work is located in a region of semi-humid to arid climate. The rainfalls decrease from the south (about 800 mm per year) to the north (about 300 mm per year) (Fig. 2). The rainy season is from May to September. The average temperatures vary from 28 to 29°C. The maximum temperatures (40°C) occur in March/April before the beginning of the monsoons.

The relative hygrometry decreases, as the aridity increases, from 80% in the south to less than 20% in the north, with seasonal variations. During the dry season, a dry northeast to east wind blows until April (the Harmattan) causing sandstorms. The diagrams (Fig. 3) show clearly the country's climatic conditions.

2.1.3. Geology

From the geological point of view, the studied sector is constituted of Precambrian rocks and Paleozoic, Mesozoic and Cenozoic sedimentary rocks. The Tertiary is called "Terminal Continental" (hereafter called "Ct"). The Precambrian crystalline rocks (granodiorites, granites, schists, etc.) occur particularly in the SW boundary regions near the Upper Volta (Liptako), in the Air mountain range and around Zinder, in the south of the country.

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The long Iullemeden basin is surrounded by the 3 crystalline mountain ranges with the east and north boundaries located outside the Nigerian territory. This basin is filled with alternating sand and clay sediments dating from the Cretaceous and Tertiary periods (Kogbe, 1973; Mensching, 1970; Machnes, 1966; Greigert and Pougnet, 1965, 1967).

The Ct extends in a long strip from Niamey to the rivers Diamangou and Tapoa, and in the south, beyond the river Niger. Ferruginous layers of the recent Tertiary period rest on the Ct and constitute elevations on the ground.

During the Quaternary era, irregularly distributed sandy areas were formed over the entire extent of the Iullemeden basin, and dunes in the north of the country. The considerable alluvial deposits of the rivers Niger and Rima were also formed during this period.

2.1.4. Hydrogeology

The studied region includes the Nigerian part of the Liptako,

that is the area located west of the river Niger and which extends to the borders of the states of Mali and the Upper Volta to the north and east, and that of Benin in the south.

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Except for the cliffs located on the edge of the plateau in the southwest and east of the Niger river, and a few inselbergs in the northern part of the Liptako, the morphology is hardly marked.

In the south of the studied region, the rocks of the crystalline base show an alteration cover of low thickness which is totally absent in the northern part.

The Ct and the alteration cover are often covered with ferruginous layers.

The unfavorable geological and climatic conditions for the renewal of underground waters, the slight extent of the reservoir rocks and the low rainfall rate, lead in extensive dry seasons to catastrophic situations as regards water supply. That is why fundamental studies were carried out on the hydrogeology of this sector in the sixties, in particular by Biscaldi (1961, 1962), Plote (1961) and Boeckh (1965) and in the seventies by Gagniere and Vadon, also by Greigert on the request of the BRGM.

There are reserves of water which may be used not only in the alteration layer and in the cover of loose sediments when it is thick enough (alluvial deposits, sand of the dunes), but also in the diacase and fracture region of the rocks of the crystalline base. The water holes with irregular flow rates which had been dug for water supply are being replaced gradually by the concrete wells of the OFEDES.¹

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According to Gagniere and Vadon, the superficial water deposits, or the deeper ones of easy access are known to the population. That is why they had proposed carrying out soundings in the neighborhood of the watering points and to determine the site of the wells according to the results obtained. Greigert carried out soundings near 60 rural centers and the pumping stations were installed on the basis of these data. This program is almost completed.

2.1.5. Soils

The soils of the Niger Republic may be divided into four groups:

1. The soils on crystalline rock in the southwest of the country are almost always deep: sandy soils and reddish-brown sandy-muddy soils. Lithosols and shallow regosols are found on the eroded areas. Beside sandy soils, clayey soils.

In the Air mountain, the origin of soils on crystalline rock

¹Office of Underground Waters. Governmental organization responsible for building wells in the Niger Republic.

has not gone beyond the lithosol stage. In the valleys of the Air, sandy or sandy-muddy soils are found on colluvial deposits.

2. In the sedimentary basins of the Tertiary period (Ct), sands, clays and maritime sediments constitute the parent rock. On the Pliocene plateaus, the soils bear laterite or iron sesquioxide covers.²

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Eolian sands are now depositing on the ferruginous layers. At the foot of the plateaus, reddish-brown sandy soils, poor in humus, have developed. The erosion-induced continual changes are the causes of the poor development of the profiles of this morphological position. The soils of the valleys and depressions range from sandy and muddy to clayey. They are occasionally flooded periodically. The dallols have very varied soils. We often find here hardly-leached brownish-red ferruginous soils rich in iron, but also rough soils, pseudogleys and vertisols.

3. The soils on sandy areas and dunes in the north and northeast parts of the country are poorly differentiated. The older pedological formations, often rich in sesquioxides are covered with Eolian sands or uncovered by erosion, according to their position. The arid climate prevents any differentiation of the profile. The ferruginous material is mixed with Eolian sands. Most often, it is rough soil.

4. The Soils on River Alluvial Deposits and Soils of Southern Dallols

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The alluvial deposits (Niger, Sirba, etc.) are formed mainly of clayey and muddy sediments. They are flooded regularly, especially in the Niger valley. Many sandy deposits are found on the banks of the tributaries of the Niger and in the dallols. The gleys and pseudogleys developed on this material, according to the hydrological conditions. When the piezometric level is high and there is no free flow, as is the case in the southern part of the Bosso dallol, saline and alkaline soils are formed.

2.1.6. Vegetation

In the Niger Republic, vegetation is determined primarily by the extent of the rainfall and secondarily by the nature of the soils. From the south to the north, the density and the wealth in species of the plant cover decrease as a function of the increase in aridity. The wet savanna becomes in the north a dry savanna, which is converted in its turn into a semi-desert vegetation, and finally we have the desert. From the point of view of flora, we find first the *Acacia combretum*, then a savanna of acacias (in

²Masses of clay, quartz and other materials, enriched in iron oxide and poor in humus, irreversibly hardened, are called "iron sesquioxides" in modern literature. If this mixture is not hardened, or if it loses its hardness in the presence of moisture, it is called plinthite. These expressions should replace the designations of laterite and lateritic (U.S. Dept. Agr., 1975, p. 50).

the transition from the wet to the dry savanna). The proportion of the Herbaceous plants suitable for pasture decreases towards the north. The region with arid climate has succulent species. They are totally unsuitable for pasture land (Bartha, 1970).

On the Pliocene plateaus, strips of vegetation appear on the aerial photographs like tiger skins and that is why they are called "striped bush" (Fig. 4). They consist of strips with and without plant cover (Janke, 1976). It is only with greater difficulty that they can be identified on the satellite pictures.

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The general division of the vegetation according to the climate is violated near the rivers and in the areas where there is a high water bearing stratum. Near the rivers and brooks, we find a vegetation richer in species than in the semi-arid region. In the dallols the vicinity of the water bearing stratum is the cause of a vegetation corresponding to better hydrological conditions. But the natural plant cover here is rudimentary. Patches of burnt land and overpasturing, especially in dry seasons, have led to the destruction of the vegetation and the negative selection of the specific composition. There remain minor herbaceous species such as the cram cram (*Canchrus biflorus*) and shrubs with hard or thorny leaves (*Acacia* spp.) which can only supply food to camels, goats and sheep.

In the agricultural regions of the south of the Niger Republic, the Gao (*Acacia albida*) is widespread. It is green in the dry season (November to April). In the rainy season, the vegetation period is stopped. The result of this phenological characteristic is that the Gao does not compete with agricultural plants for the water supply. In the agricultural areas where the water bearing stratum is close to the surface we also find the dum palm tree (*Hyphaene thebaica*) and palm-marrows (*Borassus flavillifer*). (For detailed descriptions of the botanic composition of the vegetation in different sites, we refer to Appendix I of the German version of this report).

2.1.7. Use of Lands

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The economy of the Niger Republic is determined unilaterally by the agrarian sector. More than 90% of the population (of 4.5 million inhabitants) work in the agricultural sector. The proportion of agriculture (production of the land productive animal breeding) with respect to the gross national product is about 47% (Goedicke, 1974; Splitter, 1976). In the entire Niger Republic, water is the factor limiting the development of plants.

In the areas in which the rainfall is low (less than 350-550 mm annually), dry farming decreases, and nomad animal breeding. In the Niger Republic, this natural limit is around 15°N. It is south of this latitude that agriculture is concentrated and the population density increases (Fig. 5).

Next to agriculture, productive animal breeding is of great

importance for the country's political economy. In 1976, it represented about 16% of the gross national product. Animal breeding is to a great extent in the hands of the nomads (Touaregs, Peulhs, Djermas) who represented themselves 2/3 of the breeders.

The pastures are located in the Sahel region and towards the north they reach the isohyete 100 m (Fig. 2).

2.2. Objectives of the Project and Organization

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The object of our studies was to determine new data on underground water, soils and landscapes on the basis of the interpretation of satellite pictures. The studies were carried out by a geologist in the initial phase and by
a hydrogeologist
a pedologist and
a geographer.

During the project, we wished to determine the possibilities of an automatic interpretation of the satellite data to review the situation and for the control of the cultivated regions of the Sahel, particularly threatened by desertification.

The automatic interpretation of the data of the satellite pictures was to be carried out by General Electric Company. During the preparatory work, which lasted almost all of 1975, considerable delays occurred. It was observed that the pictures furnished by the U.S. Geological Survey were of inadequate quality and could not be used for the studies. That is why orders were signed for the execution of false color pictures by the analog method to enable the work to begin. They began at the end of 1975, when we had a large enough number of pictures at our disposal. After a preliminary interpretation, we started pedological and hydrogeological studies, also work for demarcating the dry farming areas. Changes among our colleagues and delays in starting their work caused the work to be completed only in September 1978.

From September 1, 1977, we have had the assistance, provided under contract, of a member of the Hamburg Geographic Institute, from the department of Professor (Dr.) H. Mensching. He devoted himself to the extension of the dry farming areas; but it proved to be impossible to accomplish a reconstitution on the basis of the old topographic maps and the other documents placed at our disposal, as we had foreseen when we conceived the project. It was also necessary to abandon joint work on the climate and the ecological situation. In the case of meteorological studies, we had to observe that the pictures of the meteorological satellite of the Bochum Observatory did not cover the territory concerned. The sociological studies had to be given up, for they were far beyond the framework foreseen by the project.

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The automatic interpretation of the pictures was controlled by visual interpretation. Following the "U.N. Conference on

Desertification" (1977) the emphasis had to be laid on a process making it possible to control within a few years the stage of the use of the land and the state of the vegetation on a nation-wide scale, by automatic interpretation of the pictures. After repeated surveys, it should be possible to know what are the major factors of desertification and how they can be fought effectively. The characteristic of this process is the rate at which the survey is carried out; indeed the color subject maps are ready within a few weeks and may be distributed to the concerned organizations of the country.

The work was carried out in the following way:

- interpretation of the satellite pictures and establishment of preliminary maps in pedology, hydrogeology and the use of lands
- control on the site during the dry season
- revision of the preliminary maps
- control on the site during the rainy seasons
- final establishment of maps and report.

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3. Basic Principles of the Interpretation of Satellite Pictures

It is since the time it was possible to photograph the Earth from manned spacecraft during the sixties, that there is a new method of scientific research, the interpretation of satellite pictures, which permits the study of the Earth's surface. The photos taken from an orbital height are most often interpreted visually. The experiments carried out by the BGR since 1967 on the geological interpretation of satellite pictures led us to using increasingly pictures before geological, hydrogeological pedological and general exploration over certain regions. In particular it is the ERTS (now LANDSAT) program which allowed very considerable progress in this process of orbital observation of the Earth. Indeed instead of most often oblique manual photographs, we finally obtained those pictures with photographic axis perpendicular to the Earth's surface.

3.1. LANDSAT System

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On the basis of the knowledge acquired from the orbital photos of the Earth's surface, at the end of the sixties, the project of building an experimental satellite of scientific research was conceived; it was equipped with an already-known system of linear scanning (scanner) such as had been used for exploring the lunar surface.

The first geoscientific ERTS satellite (Earth's Resources Technology Satellite) was sent into polar orbit in July 1972 at 900 km altitude at a synchronous speed to the sun. It had on board a multispectral scanner (MSS)³ and a television system (RBV)⁴

³MSS = Multispectral Scanner

⁴RBV = Return Beam Vidicon

also a system for recording on the magnetic tape. The data are collected by the ground stations. If a study sector lies outside the domain of the receiving station, the data are stored by the recording equipment which is on board and transmitted then when flying over the next receiving station. Later there were other launchings of satellites of the ERTS type, in January 1975 and February 1978. From 1975, these satellites are called LANDSAT.

The LANDSAT satellites carry on board a number of sensors for which the composition of the spectral bands is the result of a compromise between the request of the botanists, geologists and oceanographers. We attempted to obtain optimal differences of values for the vegetation, and we had at the same time a fairly faithful color reproduction of the areas without vegetation. The drawbacks of this solution were accepted knowingly.

The orbit and the covering of the pictures of the LANDSAT series are coordinated in such a manner that it would be possible to cover the globe completely in 18 days (except for the regions of polar night). Each additional satellite placed in orbit was launched in such a manner as to reduce this 18-day period. Now after the disappearance of LANDSAT 1, the interval between 2 overflights of a same region by LANDSAT 2 and LANDSAT 3 is 9 days.

The RBV and MSS recording systems show basic differences. RBV gives a black and white television picture with a 20 m resolution (LANDSAT 3). This system replaced the too fragile color RBV which equipped the first satellites. On the other hand, the MSS system permits an automatic interpretation, since the data of the picture are in numerical form. The scanner technique is as follows: a rotating mirror which is in the scanner being a slit opened in the direction of the Earth's surface returns the picture in 6 beams with 4 detectors each. The amount of energy measured by each of the detectors is numbered and stored on magnetic tape or collected directly by a ground station. The 4 detectors (channels) record the incident beam on the following wavelengths:

- Channel 4: 0.4-0.5 n yellow green
- Channel 5: 0.5-0.6 n red yellow
- Channel 6: 0.7-0.8 n infrared purple
- Channel 7: 0.8-1.1 n near infrared

The mirror scans a 185 km long band, perpendicular to the line of flight, at an altitude of about 910 km. 3200 picture elements (or "pixels"). The spectral data from each element is then recorded on 4 channels. When the apparatus operates, a band 185 km wide is recorded on an approximately meridian direction. A ground station collects the band and divides it into pictures covering an area of 185 km x 185 km which overlap on the edges. Each picture includes 2340 lines and approximately 7.5 picture elements representing a ground area of 79 x 57 m (0.45 ha). Inside this elementary area, there is no possible spatial identification, since the space elements of different color (reflectance) blend into a mixed signature. The data of the reflectance of the Earth's surface are in numerized form and may be converted into black and white or color picture, or else reprocessed in computer.

3.2. Visual Interpretation of Satellite Pictures

The test band of the visual interpretation of satellite pictures is covered in the Sahel by 6 LANDSAT pictures. These scenes were taken in November 1972, April 1973 and September-October 1975. They were false color and black and white pictures on the scale of 1:500,000 with a cloud cover of less than 10%.

The interpretation of the LANDSAT pictures presents systematic difficulties:

1. They were synchronous photographs of a same region in 4 regions of the spectrum. This requires an interpretation technique different from that of the classical aerial photos.

2. The low resolution of the satellite pictures (about 79 m) with respect to the other pictures requires from the interpreter a much better knowledge of the natural conditions, especially as regards time and use of lands (Muefeld, 1976).

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But the multispectral photos have an obvious advantage over the other pictures: we could indeed obtain an increase of contrast by a color coding process, that is by superimposing various arbitrarily chosen colored documents. The increase in contrast permits in some difficult cases a sure demarcation of the different units on the satellite picture (Fig. 6). Another advantage is the synoptic view over 34,000 km², which makes it possible to recognize the relations existing between different phenomena and their surroundings, and to interpret them, which was hitherto impossible in this form.

The relatively low resolution of 79 by 57 m gives a clearer representation of phenomena occurring over extensive areas and makes it possible to take them into consideration during the interpretations for the first time. For example, it is easier to follow linear elements such as faults, which may be very important in hydrogeology, which was hitherto difficult or even impossible.

We must also consider the time taken by the interpretation of a region of 34,000 km². According to the problem and the morphological constitution of the ground, one should expect from one day to one month. If this work had to be accomplished with classical pictures, we would need 1 to 3 months. Meanwhile much more detailed data would be obtained which would then have to be regrouped in a synthesis. It is therefore apparent that the work on satellite pictures is more economic and more effective for certain studies, whereas for others, greater advantages would be obtained from aerial photos.

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3.3. Use of Automatic Data Processing (Computer)

As we had already indicated in Paragraph 3.1., it is possible to determine the multispectral characteristics of certain objects from numerical data by processing the latter on computer. If the

spectral values are defined as visual units of a map on a computer programmed for this purpose, the latter can identify all the units having the same spectral values on a magnetic tape corresponding to the picture. This interpretation may be visualized as the written expression of a certain combination of figures, or it may be recognized graphically with a printer in grey tones of a given density or in color. If an "interacting rhythm" is available, the interpretation may be controlled, varied or influenced directly by means of a TV color screen.

The considerable amount of data requires either a high capacity automatic data processing system or simple programs.

First of all we must choose the method best suitable to the problem to be treated. Experience showed that:

Visual interpretation is to be advised for geological, hydrogeological, hydrological and general geographic surveys. This will furnish the surest and most detailed results.

Automatic data processing represents an improvement of the quality of the picture if the latter is not sufficient for visual interpretation; it is also useful for surveying dynamic phenomena on the Earth's surface, such as erosion, the extent of vegetation, etc. It should be noted that the quality of the information depends to a great extent on the disparity of the units to be surveyed. The more similar they are, the less precise the demarcation, and the greater the increase in the percentage of "wrong surveys". If the units are chosen in such a manner that their discrimination is implemented without any problems, the repeated surveys can be carried out quickly and without much work by using a computer (Chapters 4-5).

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4. Results of the Work

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4.1. Geology

The purpose of the geological survey was to demarcate the sedimentary units and the Crystalline portion of the West African "shield". According to satellite pictures, the survey showed a detailed geological map which was used as basis for successive pedological and hydrogeological interpretations.

The areas of pronounced relief, for example with cuestas like around Tahoua, or the presence of laterites in the south and south west of the Iullemeden basin were particularly those permitting the identification of the catenas from the geological structure.

The satellite pictures showed clearly the Cretaceous and Paleocene units. The tertiary units Ct₁, Ct₁₋₂, Ct₂ and Ct₃ constitute, except for Ct₂, a generally well marked relief, making the demarcation easier. In the Ct₂ region, large peneplains occur which make the demarcation more difficult. Among the recent deposits,

apart from the laterites of the north of the basin, we defined the large dunes more or less stationary dunes with respect to the fields of Eolian sands which are located much further south. This demarcation is important since the stationary dunes are considered as possible reservoirs of underground water.

The Iullemeden basin is between two crystalline blocks, on one hand, the African "shield" and on the other, the Air, and both show many inclusions; we therefore sought similar structures inside the basin itself (we find a relief with rounded or circular shapes and/or a star-shaped hydrographic system). We were unable to discover such structures here. But it is interesting to observe that the subsoil of the basin shows regionally the same characteristics as the western edge of the mountain range of Adrar of Ifoghas and the Air. This hypothesis is supported if one considers the course of the dallols: it takes a north-south direction soon after reaching the basin, that is the same direction as the surrounding mountains we have just named. /30

The geological survey of the crystalline part of the studied region is supported to a great extent on the extent of the different parts of the relief. The Crystalline portion of the old Precambrian is full of peneplains and has a typical slightly sigmoidal network, which may be used for its survey.

The volcanic-sedimentary series of the middle Precambrian are marked on the satellite picture by their hydrographic system with characteristic direction and by the laterite layers covering them. These criteria made it possible for us to demarcate these units sometimes more precisely than had hitherto been possible.

Their arrangement reflects characteristically the narrow strip of the Birrimien units, which is also typical in other countries of west Africa (Upper Volta, Mali, Ivory Coast, Ghana, Nigeria and Togo). Since these series are often enriched in minerals, it is interesting to know their exact limit, not only from the pedological, but also from the geological point of view.

In Liptako, these units appear over large areas south of Yatakala, between Tera and Tillabery, also between Sebba (Upper Volta) and Niamey. The south-west extension of these soils in Upper Volta was considered promising. /31

In certain cases, we were able to identify and demarcate intrusions thanks to the hydrographic system.

Besides the geological units, we identified lineations. The latter represent probably areas of crushing which might include water resources; this holds particularly good for the points of junction of such linear structures. Their determination is particularly important for the crystalline region located west of the Niger, for the sedimentary cover (Ct₃) is very thin and interrupted there. Therefore a hydrological study can only refer here to linear structures. On the other hand, the Iullemeden basin has a continuous water bearing layer.

We were able to observe that the detailed discrimination of morphological units is accomplished more easily in arid climate, when the relief is clearly differentiated and the position of the layer is regular, as was the case for the studied region. Only the scale of the pictures then imposes a limit on the identification of the details.

The sediments of the Iullemeden basin conceal the subsoil structures. We were unable to record any correspondences between the crystalline rocks of the Liptako and those of the Air according to the satellite pictures. No sign of veins or intrusions was found.

The geological interpretation of the satellite pictures was used especially as preparation and documentation for the subsequent interpretations to be carried out. We refrained from printing the geological map obtained within the framework of this report for reasons of cost.

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4.2. Hydrogeology

4.2.1. Hydrographic Network and Dunes; Origin of Ponds

Many rivers have a linear course over long distances. It is apparent that they follow fractures of the base.

In many cases, when they reach the dune under an angle, they are diverted and follow for some time the foot of the dune which they only cross later. A dam is then formed at the foot of the dune, which is followed by the formation of large lakes, or ponds (humps of sediments). Some rivers are totally collected by the dunes. The lakes which form sometimes remain with water the whole year round, like the Kokoro pond north of the city of Tera.

Observations on satellite pictures and runs over the terrain permit the following explanation: the relatively older rivers were covered by the dunes during the arid Quaternary phase. During the humid phase which followed it, the water accumulated at the foot of the dune, stationary in the meantime. In many cases if the height of the piezometric level were sufficient, it was possible to cross the dune next to the old bed, at a place of lower resistance (constriction or lowering of the crest). This passage now represents the overflow of the natural dam (the present "ponds"). In the basin itself, sediments of different granulometry are deposited during the rainy season, according to the speed of the current. There are alternate layers of sands, muds and clays, whose maximum total thickness is 1 cm.

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Around the middle of the dry period, there is generally no longer any water in the ponds. The native population then installs a series of traditional wells to find again the water which has disappeared deep down. These wells will in their turn facilitate the infiltration of the surface waters in the humps of the sediments during the wet period which is to follow.

4.2.2. Prospective Value of the Dunes

According to the interpretation of the pictures, local deposits are expected wherever the dunes have been invaded by fossile alluvial deposits. These deposits are probably located in the presumed extension of the recent rivers forming pools at the foot of the dunes. It is assumed that fossile alluvial deposits are fed by infiltration of the waters from these natural dams, also by flow through recent alluvial deposits. It is possible that there may be furthermore formation of water at the foot of the dunes, where the level of the pools is raised artificially, or in places where pools have been created artificially, as in the case in Tera. When the level is high enough, it is possible that the surface water is infiltrated laterally into the dune. Water reservoirs may then accumulate in the deeper parts, which may be used because they are sufficiently well protected against evaporation by the sand cover preventing a capillary rise. They are probably long lasting and represent a possibility for the water supply of the population.

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4.2.3. Underground Water in the Deep Rocks of the Crystalline Period

It was possible to detect a series of linear structures by means of satellite pictures, in the sector of the crystalline base. These structures had been hitherto unknown, and their significance for the formation of water is therefore not established. We assume that they represent structures of the sub-soil and that the latter may be possible reservoirs. Such "deep" reservoirs are also protected against evaporation and they are long lasting.

4.2.4. Representation of the Results

Both linear structures and assumed fossile alluvial deposits, covered by dunes, have been detected on satellite pictures and noted on the topographic maps, reduced previously from the scale of 1:200,000 to the more appropriate scale of about 1:400,000. A precise location is therefore possible. After the NEDECO report (1965), and the more recent OFEDES programs, the centers whose need is urgent are indicated on the topographic map and the possible water supply points which we discovered by our method in the vicinity of these centers are shown there.

4.3. Pedological Surveys

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4.3.1. Preparatory Visual Interpretation of Satellite Pictures

The comparison of the satellite pictures made it possible to identify typical colors representing certain forms of landscape, the plant cover and the soils.

We first devoted ourselves to the demarcation of soil associations, that is, the group of associated soils; actually the

scale of the pictures is suitable and there are correspondences between the geomorphological limits and those of the soil associations. At the beginning of the studies, we had put forward the hypothesis that this possibility existed, and we have been able to observe that we had here a method which may be used in the future. But it must be noted that although visual interpretation permits the definition of sectors presenting characteristics with uniform signals, it does not allow the identification of pedological associations.

Visual demarcation on a picture is initially hypothetical and it may be verified or on the contrary, corrected by covering the terrain. According to the satellite pictures, important empirical data are obtained, whose probability depends on the configuration of pedological associations.

The hardened laterite ridges on the edges of the plateau are, for instance, very easy to identify: in this case, it is possible to detect geomorphological units with pedological characteristics. On the other hand, types of soils which are characterized by the diversification of their profiles in strata can only be determined indirectly by data on the surface of the ground, after establishing correlations by survey on the terrain.

The visual, pedological interpretation of the pictures certainly /36 represents a saving in time. Large areas can be covered at a glance over their full extent. So far as we know, it is possible to identify the dunes, sand fields, dallols and burnt patches of land, also the narrower agricultural units (fields), which in their turn permit deductions on the types of soils, which must be verified on the terrain. Seeing that the pedological work on the terrain can only be carried out on typical positions indicated by satellite pictures (not on soils!) for reasons of time and cost, the other positions will have to be identified by analogy. We therefore have here possibilities of error which we accept because of the time saved with this working method. We are talking of insignificant errors, in accordance with the synoptic scale with which we are working and for which we need satellite pictures.

Another of the results obtained is the partly easy identification of the linear elements of a countryside, such as the geological structures, the hydrographic network, the valleys and the roads, on condition that their spectral behavior should differentiate them from their background. From the pedological point of view, consequences may be drawn for the soils and their environment (humidity, etc.). This may also be used for an indirect demarcation of the associations. It was also possible to observe that visual interpretation, whose purpose was the discrimination of the soils, was in a large measure deductive. We have collected many facts which may be used for other studies in the Sahel and in other areas.

4.3.2. Studies on the Terrain

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To prevent serious errors in interpretation, a verification

must be carried out on the terrain to permit a development of the natural data, and correlate the colors of the picture with pedological associations and the soils. We will therefore indicate hereafter the data obtained on the terrain, related directly to the results of the pedological interpretation of the pictures.

The observations on the terrain were carried out between 11 February and 30 March, then between 17 October and 14 December, 1977. We had chosen periods permitting the observation in dry and rainy seasons. This allowed us to study the impact of the humidity of the soil on the color of the picture. It was also possible to include the impacts of the diversity of the plants, which allowed us to draw indirect conclusions on the ecological relationships between the soil and the plants. We were thus able to obtain pedological data related to the use of the soils.

An exact visual interpretation of the surfaces will depend on the following factors:

1. The existing documents: we had a map of the soils and of the occupation of the lands for certain sectors of our region; it furnished us with important data during the interpretation and for controlling our map. We obtained thus better correspondence between the interpretation and the data of the terrain.

2. The experience of the interpreter in areas of comparable climate. It was possible for him to use his knowledge of other arid regions and to obtain more exact data during the interpretation of standard pictures (vegetation, laterite layer, humid positions, etc.). /38

3. The extent and the limits of the unit of area, which is not always recognizable with the same clearness on different pictures. During the preliminary interpretation, the small areas have been sources of errors. It proved to be very hard to determine mixed signatures on the pictures because of the rapid change of the remission of small surfaces, in which the use of the land is heterogeneous. These are the cases when the most common errors in interpretation occurred. These difficulties may now be surmounted, using the automatic data processing of the picture.

4. The variable quality of the picture leads to a variable precision of the interpretation. Surfaces of the same nature appear differently on different pictures and one may therefore be tempted to interpret them accordingly. These differences may be studied on pictures which overlap on the edges.

The interpretation of certain units was impossible or very uncertain. These units were therefore studied on the terrain and demarcated. Thus we achieved the following clarifications:

-- the dark edges of the laterite ridges appearing on the picture are due both to the laterite on the spot and the accumulation of debris of the lateritic layer on the slope colluvions /39

-- the clear strips along the dallols are caused by the deposit of muddy deposit sheltered from the wind, under the lateritic cliffs

-- the differences in density of the plant cover (differences in lighting on the picture) are due to variations of humidity of the soil

-- the calcareous soils east of Tahoua (Ader Doutchi) are also covered partly by laterite; layers of gypsiferous clays, limestones and alluvia are occasionally found

-- the dark lines south of Tahoua are due to the destruction of the laterite layer (Fig. 6)

-- the clear points on dark surfaces are generally devoid of vegetation and represent cultivation in plots, or damaged areas (trampled areas around wells).

The units easiest to identify were the laterites, dunes, rivers and vegetation. Furthermore we observed that a pedological survey according to satellite picture could be differentiated to a much greater extent on the site of the deposits of the tertiary basin than on the site of the crystalline rocks. This may be explained by the division of the crystalline soil.

We give below detailed observations revealing the relations existing between the picture, its interpretation, terrain configuration and the occurrence of facts such as we had interpreted it: /40

-- lateritic layer

On the picture, the lateritic surfaces are easily identifiable, because they show dark, strange, very clear lines, 1 to 2 mm wide, representing a contrast with the clear surfaces of the generally lower levels; they are due to spectral behavior and to the morphology of the laterites. Their elimination with respect to the other units does not raise any great difficulty and it has almost never been necessary to make any corrections there. The lateritic surfaces show on the picture a color ranging from dark blue to black. The dark strips along the ridges of the layer are very apparent. Mobilization of manganese oxide gives a black tinge to the lateritic debris of the slopes, and to a strip running along the ridges of the layers. The cutting up of the lateritic surface is thus rendered particularly visible.

-- cover of sands on laterite

The remission is much stronger when there is a cover of more than 1 m sand or dust on the lateritic layer, than when this cover is thinner. The color of the picture then tends to become light yellow. The higher remission is the consequence of a higher proportion of quartzite sand. The demarcation of the covered and bare laterites is then complicated by the variable humidity of the substratum. More humid substrata appear darker on the picture. It is then possible to confuse this unit with bare units, if there are no pictures taken in different seasons. /41

-- laterites on limestones

The pictures 205 050 and 205 049 appear very dark in their eastern third (Figs. 12, 13). Bands of this color type extend

towards the west up to the sandy plane. The dark surfaces are interrupted by clear lines. The intensity of the black tinge is particularly high near the cliffs. The lines may be caused by the configuration of the soil or the rocks. According to the geological map, we know that limestones crop out in the southeast of Tahoua. We assumed that it was rendzinoid soil (mollisols). The studies of the terrain have not confirmed this hypothesis. The limestone outcrops are karstic and have no soil cover. Above the limestones we generally find an intensely colored laterite, whose color marks the entire region. The laterites are located at a high morphological level (Fig. 7) and their debris cover the limestone outcrops on the slopes. These terrains have on the whole a low remission. In some places, the limestone has no laterite cover, it may then be recognized by its typical light color in the picture. Erosion prevents any formation of soil on the limestones.

-- humid depressions

/42

Among the dark lines south of Tahoua, we identify lines ranging from blue green to reddish in color; they are formed by local depressions in which water flows. Vegetation develops very well there and differentiates them from the other areas on the picture. These lines had been interpreted before the control on the terrain as flat-bottomed basins, because of the vegetation and the dark elements contained in them.

-- eolian sands

We find in the valleys of the Ct sands which are almost always of eolian origin. Their behavior under the remission aspect depends particularly on their water content. When they are dark, they seem light, when they are humid, they are darker.

-- sand/limestone boundary

On the scene 205 050 (Fig. 12), the boundary between the sandy CT surfaces to the west and the limestones and laterites on the east appears clearly. And yet it cannot be identified morphologically on the terrain. We have not been able to solve this problem because there are no outcrops. The increase of sand cover from east to west is certainly not the only cause of the clear discrimination between these two units.

-- dallols

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The large beds of the rivers (dallols) are clearly visible on the pictures. They are filled with different sediments; the piezometric level is rather high there. The passage from the lateritic plateaus to the dallols constitutes generally an easily identifiable cliff (dark color). When there is no cliff, the dallol is characterized by its darker or lighter color, and its course. The color is caused either by a greater humidification of the soil related to a higher content of clay and humus (dark) or a higher proportion of sands (light). A light band is often

seen or the picture between the cliff and the ground of the dallols. The reflecting substance is a sandy mud coming down from the slopes; it may also be an eolian deposit of these muds after the wind falls under the cliff. On these lines, the vegetation is poor.

-- rivers, internal waterways

The wider the valleys, the more pronounced the diversification of the colors in the dallols. The dark lines in the north of the studied areas are seasonal rivers. They are small waterways whose rate of flow is not continuous over their entire length, and in which water flows only in sectors, according to the local rains. It is especially fine material, clay and mud, which deposits in the internal waterways. Unlike the clear bands along the valleys in the direction of the cliff, the bottom of the valley shows waterways with colors ranging from dark blue to black on the satellite picture. This color comes from the content of the soil in organic substances and increases in intensity when the humidity increases.

-- sands, dunes

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Sandy surfaces extend in the north of the studied region. Their high remission is due to a high percentage of quartzite sands. The surfaces showing a milky yellow tinge are covered with a recent layer of eolian sands. The thickness of the eolian cover increases towards the north. Grey to yellowish dunes are seen next to the sand surfaces. They are easy to register because of their extended morphology. They occur more often in the arid north than in the south.

-- demarcation between eolian sands and loose materials

It is difficult to define on the picture the covers of eolian sands and the loose materials above the laterites. The texture and the spectral characteristics of the laterites covered with sands are similar to those of the eolian sands; this texture is found over almost all the area of the Republic of Niger.

-- vegetation on the pasture lands

On the pastures of the Toukounou cattle raising stations (Fig. 8, no. E 1271-09374; 206 050) the same colors are observed as in the rivers of the dallols. Here the cause is not the soil (there would be sandy soils) but a relatively dense vegetation (Fig. 9). The waterways of the dallols which are located north of the station are colored, but do not have the same shape as the signals of colors of the cattle raising station. The vegetation of the waterways consists of herbaceous species which are adapted to the extreme variations between aridity and floods. In the north, there is an almost total absence of bush in the waterways. In the south, up to the confluence of the dallol with the Niger, the waterways become increasingly dark, mixed with red-brown tones. The intensity of the vegetation increases with the supply of water for the plants.

/45

-- cultivated areas

Distributed over the entire area of the studied region, we find clear spots, like points, both on the crystalline area and on the laterites with sand cover. These are fields or areas of too intense grazing in the vicinity of rural centers; they form dark points on the light spots. When there is no plant protection, the reflection of the sand appears. Errors are possible during the pedological survey, because we cannot distinguish between a sandy surface which remains without vegetation, because the ecological factors are opposed to it, and a sandy surface whose vegetation was destroyed by anthropogenic factors, which would basically have had good soil qualities. Checks may be achieved by comparing the pictures of different seasons with the older pictures.

-- bush

When the sand and/or dust cover increases, the laterite surfaces assume a blue grey tinge; they carry a vegetation consisting of bush (striped bush) with a high percentage of herbaceous species. During the rainy season, the plant cover of their regions remains clear on the satellite picture.

4.3.3. Pedological Results

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The (appended) pedological map is an important result of the pedological survey. It includes the different units of the soil, identified by visual interpretation and studies on the terrain, then checked by detailed studies; these units are classified in accordance with the French system (Aubert et al., 1967). Only the dominant units are indicated on this map. The units associated to the first, which occur on more reduced areas, are not represented, since it was impossible to integrate the study of these details with the work program foreseen. But these associated units will be indicated during the description of the primary, dominant units.

Rough Mineral Soils (1-4)⁵

The profile of the rough mineral soils is very poorly developed. Erosion and a very slight chemical alteration prevent the horizons from further individualization because of the lack of precipitations. Mechanical alteration is more considerable than chemical alteration. The rough mineral soils are located especially on the colluvial sands and deposits of the north of the studied region. Regosols, which are part of the rough mineral soils, developed on eolian sands. They cover the largest areas. Regosols are often found in valleys, on river sands. Salt deposits are often found in the basin. There are also rough mineral soils on the gentle slopes of Adar Douchi, above colluvial deposits. They are not extensive.

⁵The figures refer to the units of map no. 1.

TABLE 1
CHEMICAL AND PHYSICAL PEDOLOGICAL INDICES
OF SELECTED PROFILES IN THE NIGER REPUBLIC⁶

Lab. No.	depth, cm	level	pH, g KCl	Organic substances, *	AK, mval 100 g soil	Value of V, *	solub. (HClO ₄ * 70%)						Type of Soil	TRG, g/cm ³	nFK pH:1.8-4.2 vol. %	
							dist.	Fe oxides		Ca	dith	oxal				
								K	P							K
p. 11 rough mineral soils on eolian sands (2)																
1557	0-10	Ap1	6.4	0.2	1.8	76	31	12	150	239	175	9625	175	S	-	-
1556	10-20	Ap12	6.1	0.2	2.0	50	19	6	145	228	125	9257	176	S	-	-
1557	20-30	B1	6.1	0.2	2.0	42	9	7	260	267	125	11300	310	S	-	-
1560	70-100	C1	6.4	0.2	2.0	42	6	6	155	245	145	10450	285	S	-	-
1561	100-150	C2	6.4	0.2	2.0	43	6	6	170	196	80	9400	283	S	-	-
1562	150-210	C4	6.4	0.2	2.0	43	9	8	160	203	85	9075	230	S	-	-
p. 17 poorly developed eolian soils resting on laterite (7)																
1583	0-25	A1	6.1	0.3	2.2	27	58	3	115	32	35	5375	90	SL	-	-
1584	25-50	B1	6.0	0.3	2.2	0	29	2	195	39	0	8225	210	SL	-	-
1585	50-100	C1	6.0	0.2	3.2	13	18	3	270	66	45	11450	280	SL	-	-
1586	100-160	C2	6.1	0.2	3.3	21	13	3	205	54	55	12500	255	SL	-	-
1587	160-220	C3	6.1	0.2	3.2	25	15	2	215	70	55	13000	228	SL	-	-
p. 2 vertisols with possible external drainage (8)																
1500	0-10	A11	6.2	0.6	33.9	83	315	15	5475	187	4440	10625	1560	T	-	-
1501	10-50	A12	7.1	0.6	34.7	100	132	32	5675	284	6915	10000	1650	T	-	-
p. 9 poorly developed brunified soils (10)																
1527	0-10	Ap1	6.1	0.2	1.1	36	17	2	50	53	55	4875	85	S	-	-
1538	10-20	Ap12	6.3	0.2	1.2	8	19	1	70	73	30	4700	95	S	1.66	12.3
1539	20-35	B1	6.4	0.2	1.6	19	16	2	115	75	40	4525	150	S	-	-
1540	35-60	B2	6.2	0.1	1.9	16	37	4	215	54	45	7750	203	S	1.47	8.1
1541	60-90	C1	6.2	0.2	1.9	26	59	7	205	98	50	6300	265	SL	1.48	8.6
1542	90-120	C2	6.4	0.1	1.6	31	36	2	165	97	50	8050	365	SL	1.51	9.6
1546	120-200	C3	6.3	0.2	1.7	39	-	-	160	78	65	8450	238	SL	-	-
p. 5 hardened iron sesquioxide soils (14)																
1518	0-15	A1	6.1	0.5	4.0	10	19	8	290	69	70	4875	208	SL	-	-
1519	15-50	B1	6.1	0.4	4.4	0	9	2	300	73	35	6100	210	SL	-	-
1520	50-100	B2	6.0	0.5	5.0	0	12	5	240	87	60	25875	450	G	-	-
p. 7 hydromorphous soils, gleys on alluvions of the Niger (19)																
1529	0-10	A2	6.8	1.4	11.4	46	32	11	720	145	795	4425	3300	L	-	-
1530	10-40	A12	6.6	1.1	14.2	44	31	5	700	111	745	6625	3588	SL	-	-
1531	40-100	C1	6.6	0.5	11.5	51	16	4	460	75	610	9800	1869	L	-	-
p. 14 hydromorphous soils, poor in humus in the valleys of poor drainage (20)																
1794	0-5	Ap1	6.8	0.5	10.2	100	147	161	605	606	1400	10125	750	SL	1.61	15.6
1795	5-28	Ap12	6.3	1.0	20.2	100	38	164	605	710	3865	13250	1208	SL	1.57	10.4
1796	28-50	C1	6.1	1.0	22.7	100	41	64	595	770	4265	12125	1522	SL	1.62	9.1
1797	50-75	C2	6.0	0.6	17.6	99	38	53	621	656	2205	10125	1340	SL	1.66	9.4
1798	75-100	C3	6.0	0.5	16.5	95	36	42	575	776	2835	9375	1498	SL	1.70	10.1
1799	100-130	C4	6.1	0.5	16.5	99	39	33	590	531	2515	8625	1862	SL	1.76	8.9
1800	130-160	HC3	6.3	-	19.7	100	44	24	600	528	3535	8750	1564	SL	1.78	9.3
1801	160-210	HC6	6.3	-	18.1	100	37	32	460	530	2235	8625	1714	SL	1.79	8.5

(* = illegible)

⁶Other results of the analysis in the records of the BGR.

Abbreviations used in Table 1

T	clay
tL	clayey mud
stL	clayey-sandy mud
L	mud
sl	sandy mud
ls	muddy sand
S	sand
G	gravel (> 2,000 mm)
AK	cation exchange capacity (mval/100 g soil)
V	saturation of the bases (%)
P, K disp.	phosphorus and potassium available to the plants
P, K, Ca, Mg solub.	phosphorus, potassium calcium and magnesium (solution in HCl04) (ppm)
Fe _{dith}	iron soluble in dithionate (ppm)
Fe _{oxal}	iron soluble in oxalate (ppm)
pH	negative logarithm of the concentration of hydrogen ions
nFK	capacity of useful retention (pF 1.8 - pF 4.2)
TRG	apparent density (g/cm ³)
vol. %	cm ³ /100 cm ³
ppm	parts per million (mg/kg)
mval	milliequivalent

The associated units of this type of soils are in particular all the impoverished tropical ferruginous soils on eolian sands and iron sesquioxide conglomerates. We find fairly frequently on sites which remained humid for a long period, poorly developed soils on river sands also belonging to this group. On the other hand, the leached tropical ferruginous soils, with laterite, are rare.

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The rough mineral soils are often poor in nutritious substances and are only used for grazing purposes. Dry farming areas are most often located in the basins where there is better water drainage, for the capacity of the fields always stays low (Table 1).

The identification of the rough mineral soils is rendered easier on the color picture through the sandy substratum with clear or yellowish color. There is only rarely a plant cover, and the spectral behavior is that of the soil. We observe occasionally a slight red veil on the color picture; its presence is related to the appearance of the herbaceous species after the rains.

Poorly Developed Soils (5-7)

Unlike the rough mineral soils, the poorly evolved soils have had their profile developed. They occur in particular in the south of the studied region, where the soil remains humid longer because of greater rainfalls. The better humidification of the soil causes a relatively dense vegetation and a slight accumulation of

humus in the upper part of the soil. Among the poorly developed soils, the most extensive are those on sands and eolian sands. The lower part of the soil (-1 m) often includes lateritic material.

In the extreme southwest of the studied region, lithosols are found on the crystalline rocks and soils on the alluvial deposits along the dallols. The effect of erosion is primordial for all these soils. /48

The soils associated with this type are rough mineral soils which are found on sites of low humidity, then the rather common soils with iron sesquioxides. In the basins and the depressions where the soils are poorly evolved, soils of hydromorphous influence are occasionally found.

From the ecological point of view, these soils are characterized by their lack of depth and their low water retention capacity. There is no entrenchment which could act as barrier. The supply of substances useful to the plants is low. There is no silica solubilizable in sufficient amount in the original material.

The low clay content of these soils has also a negative effect on the supply of food substances, for there is no receiving exchanger. The poorly evolved soils represent therefore poor to medium sites for dry farming and grazing land.

On the satellite picture, it is not easy to recognize the lithosols in the southwest of the studied region. Their most common colors are red and faded blue. Rocks in distinct outcrops are surrounded by strange dark blue lines. The regions with lithosols become much clearer near the center. Pockets which have a considerable alteration cover have a richer vegetation than these soils can generally have, and they appear red on the picture.

It is relatively easy to identify poorly evolved soils on river sands because of their position along the dry valleys. A light yellowish-brown ribbon which we attributed to this class slips between the often dark plateaus and the grounds of the valleys. We were able to observe only very rarely vegetation on the latter type of site. The soils on eolian deposits over lateritic materials can easily be defined on the picture. Loose materials on laterites have a lower water retention capacity than the laterites on the spot and a medium type of vegetation forms there. These surfaces appear veiled in red on the picture. The red color is interrupted by clear lines and points of the dry farming areas. /49

Vertisols (8)

Vertisols are characterized by a considerable A level, covering directly the C or IIR level. In the Sudanese climate, pedoturbation occurs which activates the production of a thick level A. Vertisols are heavy, their structure is prismatic and their clay content more than 35%. The clay consists generally of

montmorillonite. In the region studied, the vertisols appear over a considerable area only in the Dallol Bosso, in the north of Toukourou. On the dunes and eolian sands, associated rough mineral soils are found among the vertisols. In the humid basins, the vertisols are exposed to pseudogleyification and to salt deposits.

From the ecological point of view, they are good soils. Their exchange capacity is high, as a function of their mineral composition. Except for nitrogen, they have a sufficient amount of nutritive substances (Table 1). Therefore, they have good chemical qualities, but also a much greater water retention capacity than that of sandy soils. But the occupation of vertisols is very low: this is due to their unbalanced physical characteristics. When they dry up, they harden quickly and form deep dessication slits. It is then impossible to work them with ordinary tools. That is why it happens that the vertisols are not used in Niger. The irregular hydrological situation prevents the development of vegetation suitable for grazing. These soils can only be used if it is possible to irrigate them; they then represent good sites for the cultivation of rice. /50

On the satellite pictures, vertisols occur in dark grey lines. They are easily confused with humid sites. The rapid drying of the soil after its humidification causes the low implantation observed in the studied region. After the rainy season, the vertisols are properly humidified and partially flooded. They appear dark blue on the pictures.

Soils of Steppes (9)

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They extend particularly on the eolian sands around Ouallam and are characterized by an A-C profile and in special cases, by an A (B) C profile. The A level is thin.

The associated soils are rough mineral soils on dunes and poorly evolved soils. Brunified soils are found in the depressions, and they are fairly extensive.

The humus content and the percentage of solubilizable minerals is low on sand. In spite of this they are richer than the ferruginous soils of the region. The capacity of use remains low.

In a semi-arid climate, the occupation of the land depends to a great extent on the rainfall. We therefore have here rather poor to medium areas for dry farming, but moderate grazing areas.

The soil of the steppes appears on the satellite pictures with a regular yellowish tone. We find red lines of different intensity against a yellowish background: this is the vegetation of the basins.

Brunified Soils (10)

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This unit constitutes a whole around Niamey, on the Eolian sands. The more complete evolution of the brunified soils with respect to the soils of the steppes is indicated by the ABC composition of the profile. The color of the soil is red-brown; the upper portion has a dark grey tinge through the organic substance. On the dunes, the extent of these soils depends on the duration of the humidification, from the basin up to half way up the slope. The soils associated with the brunified soils are especially steppe soils and poorly evolved soils. In the depressions, when the water bearing stratum is closer to the soil, the latter undergoes pseudo-gleyification which is an additional characteristic of the profile.

The brunified soils are used intensively, because it is easy to cultivate. They are deep and have a good hydrological capacity; they are considered medium to good regions for dry farming and good areas for grazing land. It is often impossible to distinguish brunified lands on the pictures from the steppe soils and poorly evolved soils on Eolian deposits. The background color of the brunified soils is yellowish. Unlike the steppe soils, there is a slight tendency towards grey shades. Red bands indicate more considerable vegetation and consequently better ecological conditions.

Soils with Iron Sesquioxides (11-18)

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These soils are rather extensive in the central portion of the studied region. They are found both on crystalline rocks and on the deposits of the "terminal Continental". They are strongly altered old rocks. The iron oxides are enriched in the B level, hardened and form laterite layers. The solubilizable silicates have practically disappeared. The age of the laterites may be classified as Pliocene, even though it remains difficult to achieve a chronological classification. They were reworked in a recent period by winds loaded with sand, and reorganized by different factors.

Three groups are distinguished in the class of "iron sesquioxide soils". In the west and east sectors of the studied region, the greatest area is covered by the group of "hardly-leached tropical ferruginous soils" and "impoverished tropical ferruginous soils". The original material and the pedogenesis then define more advanced division.

The hardened leached tropical ferruginous soils (14) and calcic soils (13) extend over a certain area in the west and east of the studied region. These soils are reorganized by erosion and give the "depleted tropical ferruginous soils" (17, 18).

The extent of the group of poorly evolved ferruginous soils is limited to the dallols. The original Eolian material has undergone a fluvial reorganization. Humidification of the soil over a fairly long period leads to the formation of pseudogley (11) and soils with supersaturation of bases.

"Iron sesquioxide soils" are accompanied by poorly evolved soils and rough mineral soils, above leached tropical ferruginous soils on local sand banks. In the depressions, brunified soils are also found. In the dallols, especially around Filingue, we find brunified soils and poorly evolved soils, in the depressions, vertisols; around closed lakes and on the shores of the discharge waterways some saline and sodic soils, also gleys.

From the ecological point of view, these soils are minor, for they are easily altered. According to whether the material was inherited or brought in, however, the ecological value of each of the units of this type must be considered in detail.

The hardened leached ferruginous soils cannot be cultivated. They are shallow with a low volume of roots, they are poor in nutritious substances and dry. Dry farming is impossible. The "striped" bush (Chap. 2.1.6.) is a typical vegetation of the lateritic regions and gives a poor grazing site. The content of phosphorus and potassium (soluble in HCl) available to the plants, and the organic substance content is extremely low, the exchange capacity is greatly reduced, the proportion of iron soluble in dithionite (Table 1) is fairly high. The hydrological conditions are irregular, but they may be improved by a cover of Eolian sands and by the lateritic layer, for the latter prevents the run off of waters. The iron sesquioxide material is used in the Niger especially for road building.

The depleted tropical ferruginous soils on Eolian sands and laterite debris (17) in the north of the studied region are also sites unsuitable for cultivation. But the rainfalls are already too low for dry farming.

On the other hand, the soils of the dallols are very valuable to agriculture. They are sandy, sandy and muddy and muddy soils, which, according to their position on the terrain constitute good to very good sites for cultivation. The diversity of the soils and their inherent ecological value are represented in Fig. 10 on a cross-section of the Dallol Bosso near Birni Ngaoure. The high population density near the dallols is a sign of their favorable ecological conditions. In particular, the water supply to the dallols is better than elsewhere; this is due to a higher proportion of fine material. The areas which are not used for dry farming are good grazing areas. The humid areas represent alternative pasture grounds, especially at the end of the dry season, except on salt deposits. If the piezometric level is high enough, modest irrigated cultivation can be carried out. One should use this possibility of irrigation to produce fodder so that the cattle should have enough feed to get through the last few weeks before the rains.

The diversity of the soils with iron sesquioxides is great. It is not always possible to identify the different units on the picture. Only the comparison of several pictures taken at different times and control on the terrain make it possible to distinguish groups from subgroups. The dallols, because of their elongated

shape, also the laterites, are easily recognizable.

The sandy color of the dallols varies within their very limits, according to the change in their substratum and different moisture rates of the soils. The surrounding landscape is generally of a color ranging from dark blue to greenish-blue. /56

We see in the dallols themselves blue green to reddish-green strips. They come from more humid run off waterways, where the vegetation is more abundant than elsewhere, in the dry valley. Between the deeper waterways in which hydromorphous soils are located, regions of yellowish background occur with light spots. These are dry farming areas of the dallols on poorly leached tropical soils.

Hydromorphous Soils (19, 20)

Hydromorphous soils include gleys and pseudogleys. They extend over the banks of the Niger, its tributaries, in the depressions of the dallols and in the valleys of the Ader Doutchi. The gleys are characterized by the formation of an oxidation (Go) or reduction (Gr) level, whereas the pseudogleys are characterized by areas of marbling, that is alternation of Go and Gr spots.

The gleys occur particularly on the banks of the Niger and the downstream areas of its tributaries such as Sirba, Dragol and Goroubi. The phreatic layer remains fairly stable. An obstruction is observed in the valleys of Ader Doutchi. The soil remains humid fairly long and causes pseudogleyification. Brunified soils accompany hydromorphous soils; they are found on the sand banks of the Niger shores; the associated pedological units are vertisols and the soils of salt deposit areas. /57

From the ecological point of view, hydromorphous soils are good. They receive an adequate supply of phosphorus and potassium. Their value as cultivation site is diminished by unbalanced hydromorphous characteristics. Flooding represents a permanent danger on the banks. Furthermore, the aeration of the gleys is not satisfactory, even when the water is drawn away from the surface, because of the soil's hydromorphous capacity and the low infiltration rate (Valet, October, 1975). Hydromorphous soils represent therefore extremely favorable sites for rice cultivation; well-conditioned irrigation may permit several crops every year. Aquatic rice is now being grown over a large area of the alluvial deposits of the Niger. The uncultivated areas are used for nomad grazing during the dry season.

Hydromorphous soils are easily recognizable on the satellite pictures. They are humid regions along the light blue waterways, with a dark blue or red strip, according to whether we are dealing with humid soils or vegetation. It is impossible to demarcate gleys and pseudogleys from the pictures; knowledge of the terrain and a documentation on the phreatic layer are indispensable.

Sodic soils play a secondary role in Niger. We have not made any subdivisions in saline or sodic soils (comp. Richards, U.S. Dept. of Agri. Handbook no. 60, 1969). We were able to observe a small sector around Birni Nkonni with saline and sodic soils. They are found especially in closed depressions or on the sites in which the phreatic layer is high, like the southern parts of Bosso and Maouri dallols. They are therefore associated with gleys and pseudogleys.

It is generally impossible to use these sodic soils. According to the salinity, various halophile plants are found there. They are occupied intermittently by pastures, at the end of the dry season. The animals need minerals, which are supplied to them by salt crystals.

It is rarely possible to identify sodic soils on satellite pictures. The low plant cover is an indicator which may be used to define hydromorphous soils, with which they are most often associated. It is absolutely necessary to be acquainted with the terrain and have data on the situation of the phreatic layer to define these 2 classes.

4.4. Extent and Dynamics of Dry Farming

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Dry farming is practiced in the south of the Niger Republic. Their northern limit ranges from the national border of Mali in the northwest part of the Niger Republic to Nguimi, passing through Tahoua and Tanout. This limit is practically identical to the annual isohyete of 350 mm. Further north, dry farming areas are only found scattered in valleys and depressions, where the water supply to the plants is more favorable. The crops are increasingly uncertain towards the north. In Niger, apart from dry farming, the forms of use of the soils are irrigated cultivation and pasture. It is not always possible to accomplish a sure division of these three forms according to the satellite pictures.

4.4.1. Visual Interpretation of the Satellite Pictures

The pictures we had for the survey of dry farming came almost entirely from overflights in dry season. We therefore turned to the study of the agronomic conditions.

We had to start our work of interpretation of pictures by comparing the latter with the official topographic maps, in particular the map on the scale 1:500,000. It is possible that around the population centers indicated on this map, certain areas identifiable on the map may be used for dry farming. We have been able to observe clear spots on the pictures near these villages.

The often angular limits of the fields permit a demarcation

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with respect to the regions which show a similar spectral behavior. This is important because specifically in the dry season, it is the substratum, generally sand, which conditions primarily the reflections; actually the harvesting and the distance between the millet stubble fields make the plant cover transparent. The distance between the stubble fields depends on regional and climatic differences, also the annual rainfalls. Therefore, to analyze the LANDSAT pictures which were taken over several years, we must obtain data on meteorological conditions (rainfalls) before the recording.

Here is an example:

During the work on the terrain, we observed different densities of the plantations. In the south, the distances are less great than in the north. In humid years, we may observe distances less than 10 cm. The decrease of the rainfalls towards the north causes a natural drop in the density of the plants.

During the vegetative period, it is easy to identify the extent of the green plants on the near infrared of the pictures. That is why the color pictures available to us show a red color on the geometric shapes in the areas in which a living vegetation exists. During the interpretation, one should respect differences due to climate. Therefore the local episodic rainfalls are represented on the pictures by their corresponding red color. It is nonetheless clear that the absence of red color does not necessarily prove that there is no dry farming. These difficulties must be overcome by making use of a series of pictures taken at different times during the rainy season. /61

Settlements represent another criterion of identification of the dry farming, for they almost always appear as black points among the white spots which we had already mentioned.

Certain difficulties arise in the comparison of the satellite pictures and the official maps, for we see on the pictures light spots over large areas, which do not correspond to anything on the maps. On one hand, they are small settlements not shown on the map, on the other hand, abandoned fields which had belonged to dead settlements. (We know that rural centers shift or are suddenly abandoned.)⁷ But we have also been able to recognize on the maps that the light spots sometimes represent damaged areas surrounding the wells. Actually the herds of cattle often go towards wells or pools, and the trampling of the animal hooves destroys most of the vegetation on a diameter of 10 km around the watering points. The immediate vicinity of the wells is absolutely bare.

⁷The resolution of the LANDSAT pictures (Chap. 3.1.) does not permit the sure identification of each field. The density of the fields and their areas decreases when their distance with respect to the settlements becomes considerable.

The wells are precisely the critical points in questions of desertification. The daily passage of the herds destroys the vegetation and gives the ground over to deflation. The deep wells dug in the north of the country are the point of assembly of a semi-permanent population, of which most of the inhabitants remain nomads. For greater simplicity, the water supply forces them to undertake only reduced shifts. This also leads to the destruction of the vegetation surrounding the wells.

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The resolution of the LANDSAT pictures leads to generalization of the content, so that the interpreter is not overwhelmed with data as is the case for aerial photographs, but certain details disappear. The latter include the ratio of cultivated areas, the unploughed land to the areas without vegetation. We know that there is generally a three-year cycle. But it is impossible to analyze this process except by taking systematic surveys every year. This work would be absolutely necessary for a better knowledge of the phenomena of desertification.

But one should not diminish the importance of the generalization of the content of the pictures, for it makes it possible to grasp very quickly and over large areas relationships between different factors and units.

The picture elements of 79 X 57 m which represent details appear in mixed signals whose content is not always clear, even after comparison with the terrain. Furthermore, the LANDSAT pictures are comparatively vague, which perturbs the demarcation of certain units by visual interpretation. The increase of contrasts may be used to remedy this.

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The dimensions of the picture elements of the multispectral LANDSAT pictures of 79 X 57 m prevents the identification of 10 to 15 percent of the areas used for dry farming. More reduced irrigation plots, such as for instance the horticultural cultivation of the Dallol Bosso or the banks of the ponds appear in the best of cases only with mixed signals. We were able to make a survey of the Dallol Bosso from work on the terrain, but we were only able to represent the mixed regions on the map. In the other sectors, such plots cannot be taken into consideration. Since they were not very important for the Niger economy, this seemed to us acceptable.

The identification of dry farming areas in the north is not absolute, for it is the substratum which is the most important reflection factor, since the implantation density is low. Unlike the temporarily green landscapes (grass) of the same latitudes, the red veil (on false color pictures) of dry farming areas will be much weaker and can even be absent.

The identification of dry farming areas on the dry season pictures in the south is distinctly surer and easier because of the contrast of vegetation. Indeed, the latter is much more dense in the south and it has more effect on the reflection. We show an example on Fig. 11, on a detail of the satellite picture south

of the Dallol Bosso.

In the extreme south of the Niger Republic, the identification/64 of the unploughed areas is complicated by a "superimposed" red veil caused by the vegetation covering the fallow fields. Dry farming is not very important, however, because of the prevalence of lateritic soils; now cultivation is only possible on the sites on which there is a good sand cover, especially in small valleys and in the depressions. Furthermore the dimensions of the fields decrease considerably and visual interpretation, while still possible, requires a lot of time. Mixed signatures dominate in the regions beginning 50 km south of Dosso, and it is no longer possible to interpret them with certainty.

In the area of the laterite plateaus, millet is cultivated particularly in the valleys and depressions. That is why these fields extend in the Dosso area, like a narrow ribbon several km long.

Dry farming is favored by large stretches of Eolian sands, where they cover large areas. On the other hand, the dunes represent linear sites where the thickness of the substratum is a limiting factor for implantations.

As may be seen on the satellite pictures, in the north of the studied region, there is alternation of sandy areas and lateritic elevations which appear as dark lines on the pictures. On these lateritic spines, cultivation is only possible in the flat-bottomed basins. The fields are too small to be identified on the pictures.

The fields on eolian sands are often planted with millet. They are larger because the crops are poor and a large area is needed to obtain the food required per person. These sectors have a high reflection and appear clearly on the pictures. In the Tahoua region, the sand is mixed with small balls of laterite and sometimes seems dark. /65

4.4.2. Work and Control on the Terrain

Within the framework of the interpretation work in connection with the dynamics of dry farming, just as for the pedological interpretation (Chap. 4.3.2.), two trips were carried out on the terrain. The trips were carried out both by car and by plane; it was thus possible for us to observe a part of our terrain in the same prospective as the LANDSAT, and to include in our work distant regions or areas of difficult access, which would have been impossible on the ground, in view of the short time left to us and the very loose road system of the country.

The first trip on the terrain took place in the middle of the dry season (January to March, 1978), which permitted a contrast with the LANDSAT pictures. But the interval between the LANDSAT recordings and the work on the terrain was 5 years. The object of these trips on the terrain was to control and correct the survey

of the dry farming carried out in Germany. To this end, representative regions had been divided according to the preliminary interpretation. We refer to the vicinity of Niamey, Filingue and Tahoua. Starting from these cities, trips were carried out over more extensive regions, so that nearly all the region to be studied was analyzed.

The second trip was carried out during the peak of the rainy season, in August-September, 1978. Our purpose was to complete the results obtained on the dry farming areas at the end of the rainy season. It was possible to draw important conclusions on the phenological behavior of millet. Meanwhile we defined test regions for automatic classification of the pictures. It was possible to specify the validity of the classification and its units. At the same time, the BGR suggested resuming the survey of the region recorded by LANDSAT, so that we had a direct correspondence between the data of the satellite pictures and the observations carried out on the terrain. These studies are now in progress.

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4.4.3. Results

1. For the first time, a survey has been given of the dry farming areas according to the LANDSAT data and their interpretation, for the western part of the Niger Republic (map no. 2).

2. It was observed that the dimensions of the field and their density undergo considerable variations with respect to "natural" vegetation. This is particularly important for automatic data processing.

3. It is impossible to obtain a sure demarcation of the present dry farming areas and unploughed lands or other surfaces devoid of vegetation except by comparing several pictures of a vegetation cycle.

4. It now seems to us possible to achieve a regular control of the endangered areas of dry farming and their surroundings.

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4.5. Irrigated Regions

Irrigated regions have been established particularly on the alluvial deposits of the Niger. We also find irrigation areas in the Dallol Bosso and the Ader Doutchi (Keita, Galmi).

It is rather easy to define irrigated surfaces on satellite pictures. The soil is more humidified and appears dark blue to black on the picture, as long as the vegetation is not too dense, for in this case, the red colors dominate. The irrigated areas therefore appear red when the vegetation has reached a certain density.

The water supply of the irrigated areas is more regular than that for dry farming. The plants of the irrigated areas remain

green longer. This characteristic may be used at the end of the rainy seasons for the survey. If water is drawn from an artificial lake, its extensions behind the dam is an additional criterion for the identification of the irrigated regions. The fields are generally still red when the water level disappears. This change can be observed very well on the pictures. We were able to note particularly easily the irrigated areas north of Keita. The green color is clearly differentiated on the dry surfaces of the surroundings (Figs. 12, 13).

In the humid regions of the alluvial deposits of the Niger, it is difficult to determine with certainty the areas of irrigation. We must have pictures taken at different times to distinguish rice fields from natural vegetation (grasses). /68

4.6. Pastures

In addition to dry farming, the population practices cattle breeding on a nomadic basis. The sedentary flocks are tended by shepherds in the vicinity of the rural settlements. The nomads pursue their traditional ways, northward in the rainy season and towards the south in the dry season.

On the satellite pictures, these routes cannot be seen directly. But the signs of grazing are visible over the entire stretch of the studied region. They constitute circles devoid of vegetation around watering points (wells, pools) whose number increases after new deep wells were dug in the north. They also include signs of natural degradation parallelly to the increase of the animals in the herd (even during the drought of 1968-1973).

This degradation applies not only to the graminacea (replacement of associations of graminaceae by herbacea whose lifespan is 1 year, see Appendix), but also the vegetation of the bush. People also attack the trees which they fell to have wood to burn. It may be added that the millet straw is also used for fodder which causes quite often conflicts between nomadic cattle breeders and the settled cultivators before the harvest.

All this leads to the clarification of the picture. We were able to verify this phenomenon thanks to the Toukounou animal breeding station, installed with German cooperation in the Dallol Bosso north of Filingue. A regeneration of the vegetation took place since the station was established; it is a cattle breeding station covering an area of a few km². One cattle unit (500 kg) corresponds to 8 ha meadow per year; this area was also proposed by the UNDP for these latitudes. These pastures adapted to the country's situation also made it possible not only to resume the graminaceae, but also that of trees. This is apparent on the pictures from the darker shade (Fig. 8). /69

There is another example: the Ekhrifane cattle breeding station, much further north.

These two sectors permit a direct comparison between the degraded vegetation and its regeneration as a result of organizational and ecological measures (Fig.).

4.7. Application of Automatic Data Processing to Control the Dynamic Phenomena /70

The possibility of measuring the reflections of the Earth's surface and the conversion of these data into numerical signals are the condition of their automatic processing. The precision of the whole LANDSAT system makes it possible to use these recordings of the Earth's surface for cartographic purposes, in the broadest sense of the term.

The great advantage of the satellites of the LANDSAT system is that they fly over the Earth at regular intervals on always identical orbits. The use of several satellites offers prospects whose importance can only increase, especially in the sector of control of the dynamic phenomena on the Earth's surface.

Examples:

- control of dynamic phenomena on the coasts: shifting of the sands (Hoppe, 1976)
- control of the variations occurring in the forest regions of the Tropics and the temperate regions (Morain & Klankamsorn, 1978)
- control of the ecological development of the areas affected by desertification (for instance Berry & Ford, 1977; UNCOD, 1977)

The problem of selecting measures against the spread of the desert is an example of the application of the space technology of the present and future research satellites in view of obtaining elements in the struggle against desertification.

4.7.1. Description of the Test Regions

/71

1. Criteria on Which the Choice is Made

For automatic processing of the pictures, we determined, then studied several test regions during the second trip on the terrain. These terrains must satisfy several conditions:

1. be accessible rapidly and in all seasons
2. be clearly definable on pictures and maps
3. combine the largest number of characteristics presented by the landscape and the use of land in Niger

Furthermore, there had to be a good coverage of the terrains by the LANDSAT pictures, both in time and space.

The orientation on LANDSAT pictures requires the presence of marking elements on the terrain: the ridges of the lateritic plateaus and the water levels offer good identification criteria.

Here is the detailed list of the test regions selected
(map no. 2):

Karma (1)

/72

The Karma region extends to about 40 km northwest of Niamey and is accessible through a good tarred road. The banks of the Niger are widened and are used as rice plantations over a fairly extensive area, which is clearly visible on the pictures (red). The numbering of the pictures permitted a more thorough differentiation; distinguishing the fields under water and the dry fields. Towards the north, the banks are clearly bounded by a laterite layer. Attached to it is a 2 km lateritic surface, covered with a thin layer of sand; it is not used for purposes of dry farming. Herds (sheep, goats, cattle) destroy the vegetation of the "striped bush", which is already very poor. The plateau dips slightly towards the north to form a tributary valley of the Niger which does not always carry water, even in the rainy season. Ponds have been formed there whose water level undergoes considerable variations during the year. These ponds retain sufficient humidity in the soil, even in dry season, to permit the subsistence of a dense vegetation. The inhabitants use these sites for small horticultural cultivation areas.

On the slopes of the windward valleys, when the sand layer is thick enough, raceme millet is grown. When the water supply is properly assured, the ordinary millet is cultivated.

South of Niamey (2)

/73

The only region located on the south bank of the Niger, includes, apart from the river banks, an old line of dunes quite visible on the LANDSAT pictures, also its junction with the lateritic plateau. A valley where heaps of sands have accumulated falls into the Niger.

The banks of the Niger are used partly for cultivation of rice: it is concentrated most often on the abandoned arms of the river. Small irrigated islands are of no importance, they are located on the wettest part of the bank and are shifted according to the water level. Millet cultivation is limited to the valley which we had mentioned and to the lower portions of the dunes. Between the dunes and the river we observed extensive plantations of dum palm trees. The tops of the dunes do not carry any vegetation. The profile of the vegetation from the foot to the top of the dune is found again on the terms rendered by automatic data processing (Janke, 1972, pp. 57 ff).

The state of the vegetation of this region presents a characteristic: the numerical interpretations already show a better state of the vegetation, especially that of the "striped bush". We first thought that was due to the local rainfall. But work on the

terrain showed that the shape of the degradation and partly the association of species are different than on the north bank of the Niger. Here the plants reach at least a man's height, and their density is greater. But the grass cover has suffered considerable damage. There is no nomadic cattle raising south of the Niger, because the river constitutes a natural barrier. The proximity of the city of Niamey does not affect deforestation, for the fixed bridge has only been installed not long ago in this region. /74

It would therefore be natural to consider this sector as a test region for desertification. On one hand we have here a relative scale of comparison for the spectral behavior of a hardly degraded vegetation, on the other hand, we were able to check directly the changes in the vegetation as a result of deforestation, etc., on satellite pictures.

Boubon (3)

This region is characterized by the narrow banks of the Niger, almost without cultivation, by a steep slope rising towards the lateritic plateau and by a narrow valley becoming wider towards the north. We find there a pond with cultivation of leguminous plants. The terms of automatic data processing represent small water levels which could be observed during the rainy season. Millet cultivation could only be identified on the accumulations of sand on the slopes of the valleys exposed to the wind.

Kone beri (4)

/75

Here differences in relief are very small. The highest points are old dunes exceeding their surroundings by at maximum 15 m. There is no salient morphological detail to help in the orientation. A river (light sands of the valley) may be of some help, but it changes its course every year.

Vast areas are cultivated with millet. We observed graminaceae 1 m high on the dunes during the rainy season, which indicates rare pastures. Trees and bush are rare near the population centers, for they have been used for their wood. The terms of automatic data processing are classified homogeneously.

East of Niamey (5)

This region has not yet been evaluated by computer. On the terrain we distinguish 3 principal elements: the "striped bush" on the laterite plateaus, with extensive grazing lands. These plateaus are not bounded by a cliff, but by gentle slopes where the "Cram cram" (*Cenchrus biflorus*) grows during the rainy season, and representing a steppe with graminaceae reminiscent of the savanna. The sparse forestation (species of acacia and combretum) forms a light higher stage with distances of implantation of more than 50 m. This savanna includes many fields of millet. The fields /76

are not all used every year; there is always a part which is fallow. On the fallow areas, "wild" millet grows from disseminated seeds. These "wild" cultivations of millet have irregular distances of implantation.

Aviation Forest (6)

We had intended to include this area in our studies. But a first survey showed us that azonal plants and trees are found, in particular different species of eucalyptus which are atypical for the African Sahel.

Millet fields extending up to the banks of the Niger are adjacent to the south of the forest region. The banks are now transformed into rice fields. The sectors which are not dammed are used as grazing lands.

Keita (Dept. of Tahoua)

South of the city of Keita, we find a partly artificial perennial pool. It supplies water for an extensive irrigated surface and various leguminous plantations. The abnormally high 1978 rainfalls (485 mm by August 20 in Keita) destroyed this pond during the rainy season.

The slopes of the Keita basin are areas of cultivation of millet /77 with clusters when the sand layer is thick enough. By comparison with the regions further south, the implantation density is lower (interval of up to 1.50 m) and the reflectance is that of the sand.

At the top of the slopes, there is practically no vegetation, except for small xenophytes. The cretaceous rocks show through the surface. The area in steps of the Ader Douchi is covered over vast stretches by a lateritic layer (Fig. 7).

4.7.2. Problems of Control of Desertification in the Sahel

The changes in the environment, the source of food for men and animals, have reached such an extent in the Sahel region, that one must expect serious damages of the ecological balance in case the periods of drought are too long.

It was observed that the anthropogenic effect, especially when associated with low rainfalls and sandstorms has fatal consequences for the vegetation of the dry savannas: the denudation of the soils, whose yield had already been low, and the destruction of the substratum of the dry farming areas. The natural vegetation, which is used as fodder for cattle and wild animals, has also very slim chances of finding new roots on these areas. The consequences are the clearing of entire regions, which lose therefore all their value with regard to food for men and animals.

In the "Draft Plan of Action" (UNCOD 1977), we established a list of the main indicators of the beginning of disturbance of the ecological balance preceding the desertification. To this end, we must establish the extent of the following areas:

- areas used already or which may be used for cultivation
- grazing land
- forests
- extractable underground water
- usable surface waters.

Note that the estimates of the natural resources must be followed by a permanent control of their factors. To this end it is absolutely necessary to apply modern technologies (satellites, aircraft, ground stations with automatic recorders).

It will be possible to establish the exact spread of the deserts and to carry out long-term observations in an indirect manner. To this end, we propose a plan of action for the observation of the units and following physiographic situations:

- X: atmospheric phenomena
- X: distribution of the vegetation and soil cover
- X: transport of dusts
- X: movement of the sand dunes
- distribution and displacement of wild animals
- nutritional condition of the cattle
- X: distribution of cultivated areas
- crops
- X: extent of irrigated areas

Within the framework of this study, this list may be completed by the following points:

- X: distribution and extent of stagnant waters, ponds, lakes, dams
- X: search for water flowing throughout the whole year or part of the year
- X: distribution of bare soils

The units preceded by an X may be identified on satellite pictures. The space ratio of these units to one another gives a survey of the effects of the spread of the deserts on a small and large scale. It will be possible to estimate the dimensions of the area of desertification and its development when comparative studies have been carried out over several years; we will then have available reliable data. So far, we are reduced to assumptions. The results of these studies must be presented on thematic maps.

4.7.2.1. Example of Classification of Numbered Image Data to Demarcate the Units of Use of the Soils

We used 2 programs of the program system RSERTS 2, developed for a TD installation of the type Siemens 4004/135 (BS 1000 system) to classify numbered data. The RSERTS 22 program furnished, for the desired detail of the picture, for each domain of the spectrum, the

distribution of the intensity of reflectance on a histogram with cumulative curve (Fig. 14) and the 6 planned projections (4/5, 4/6, 4/7, 5/6, 5/7, 6/7) of the intensity distributions in a four-dimensional space (Fig. 15).

The choice of suitable test regions makes it possible to obtain, /80 by an iteration process the typical characteristics of reflectance of specific units (Tables 2 and 3) using the RSERTS 22 program.

If one orders different alphanumerical characteristics for similar reflection characteristics, the RSERTS 23 program presents a pseudo-map for a part of the picture. Counting of the points of each of the units permits the almost quantitative evaluation of the dimensions of the area.

4.7.2.2. Results of the Classification

The visual interpretation of the pictures was completed by automatic data processing to obtain the following units: sand, laterite, humid surfaces, and surfaces covered with vegetation.

Figs. 16 and 17 show a detail of the terrain located 30 km southeast of Filingue and 45 km southwest of Niamey with the types L (laterite), + (sand), = (dry soil) and 8 (vegetation). The intensity values recorded on channels 4 to 7 for the 2 test regions are indicated on Tables 2 and 3. These tables show that the spectral values of a picture cannot be exchanged with those of another scene. They must be reestablished for each new region, because of the differences in climate, vegetation and soil. As shown by Tables 2 and 3, the spectral values do not coincide for the indicated units, which permits a satisfactory discrimination.

TABLE 2
INTENSITIES IN THE CHANNELS 4-7; AUTOMATIC CLASSIFICATION
30 KM NORTHEAST OF FILINGUE

Unit	Signature	Values of intensities in the channels			
		4	5	6	7
Laterite	L	51 - 61	63 - 72	61 - 80	27 - 37
Sand	+	78 - 87	99 - 110	93 - 105	41 - 46
Dry Soil	=	60 - 66	77 - 92	80 - 92	35 - 40
Vegetation	8	33 - 41	27 - 39	49 - 57	24 - 30

TABLE 3
INTENSITIES IN CHANNELS 4-7; AUTOMATIC CLASSIFICATION
45 KM SOUTHWEST OF NIAMEY

Unit	Signature	Values of intensities in the channels			
		4	5	6	7
Laterite	L	39 - 44	40 - 49	50 - 55	22 - 25
Sand	+	55 - 67	66 - 87	74 - 87	33 - 37
Dry Soil	=	44 - 54	47 - 63	56 - 68	24 - 31
Vegetation	8	33 - 41	27 - 39	49 - 57	24 - 30

TABLE 4
ANNUAL EVAPORATION (V) AND RAINFALLS (N) IN NIAMEY AND TAHOUA

	Niamey	Tahoua
V	2057	2307
N	571	390

A reduction of 1/200,000 was achieved according to the LINOSCAN process of the GESOC of DFLR (Deutsche Forschungs-und Versuchsanstalt für Luft-und Raumfahrt⁸) in Oberpfaffen, followed by a photographic reduction of the negatives (Fig. 18). It may generally be affirmed that the units which stand out clearly from their background on the color picture, are grasped and also identified by automatic data processing. We refer to the following units: irrigation surfaces, water level, sandy surfaces, areas covered with vegetation and lateritic plateau. The final stage of this process is the automatic establishment of thematic maps within a very short time, after repeated overflights.

⁸German Aeronautics and Space Research and Test Center

4.7.3. Repeated Surveys of Regions in Danger of Desertification

In the Sahel, between the Atlantic and the Republic of Sudan, an area of 2.75 million km² is threatened by the spread of the desert. According to the United Nations, formerly productive soils in the south of the Sahara have been converted into desert in the past 50 years.

There are no precise figures on the present spread of the desert, only uncertain and speculative estimates. What is sure is that we must know clearly where measures should be applied against the spread of the desert so that they be more effective.

That is why we studied, within the framework of the project, the possibility of a consecutive survey of regions threatened by drought. As we saw in Chap. 4.6.1., it is possible to obtain data on the extent, and through the mutual relation of certain units, data on the "rate" of desertification; the above-mentioned data may be taken from satellite pictures and used for map-making.

/82

The conditions making it possible to obtain over vast regions a reliable map of the land threatened by the spread of the desert are known theoretically, but they have not yet been tested practically in the framework of their interaction.

a. Recording of the Data: it may be achieved by the satellites for the study of the terrestrial phenomena of the LANDSAT type now in action.

Seeing that the main interest resides in the vegetation (natural vegetation, fields, irrigated regions) and water resources (rivers, dams, lakes) in relation to the shift of the dry areas, it is desirable to record data during and soon after the rainy season.

b. Collection Station: important link in the data transmission chain. Outside the U.S., we now have stations operating in Canada, Brazil, Italy and Sweden. Other stations are foreseen in Zaire, Upper Volta, India, Indonesia, Australia, etc.

The LANDSAT system is now operating by recording the data noted outside the reception areas of the stations. These data are then collected from magnetic tapes when flying over the reception stations of the U.S.

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c. Preparation of the Data: after reception, the data which are in numerical form are converted into color pictures in several stages and into "Computer Compatible Tapes" (CCT). The calculations of the correction for the site of the picture, the Earth's rotation, the instability of the signal, etc., are long and complicated. In order not to be compelled to take into consideration all the special requests of the interpreters, which would lead to interruptions each time, they have decided in the U.S. to accomplish "pipeline processing"; each scene is subject to a maximum number of stages which always represent the latest standard of technology and which

allow the user to have the optimal working base. The enormous amount of data passing through this "pipeline processing" and the increasing number of users of the LANDSAT data led to a 6-month wait between the recording of a region and the distribution of the terms to the users.

The second generation of geoscientific research satellites, planned for the eighties, will provide a greater resolution and more numerous recording channels. This will cause nearly 20 times the increase in the number of data. The delays due to image processing will then probably reach proportions which will no longer permit this technological potential to be used for up-to-date research.

d. Data Processing: the numbered spectral data are used for demarcating the units indicated in Chap. 4.7.2., preceded by the X. The following procedure is adopted: the test regions for which the use of the lands is known are analyzed to determine the mutual ratios of the intensities. If necessary, these test regions are studied on the spot, and a survey of the situation is conducted. When these regions are clearly identified, we achieve a synthesis of the different spectral combinations through an electronic program. The original tapes (CCT) are reprocessed by this program in such a manner that all the areas in which there are specific spectral combinations are identified. /84

There are different processes of visualization of automatic data interpretation:

- screen
- listing printer
- printing of maps

Seeing that in the case of the spread of the desert, the spatial distribution of each of the units of use of the lands is particularly important for planning and control, it is absolutely necessary to render the data in the form of maps.

e. Establishment of Maps: there is always an obstruction at the level of the establishment of maps, before use and the distribution of data for planning. Even in the overpopulated areas of the industrialized countries, the maps generally represent a lag of 5 to 10 years on the existing situation. The printing of the maps after presenting the model also takes time: according to the printing method chosen, from 4 months to several years. /85

For geological maps indicating the distribution of the rocks, this is a static phenomenon and the delays, though regrettable, do not have serious repercussions. For detailed topographical maps or thematic maps, and especially to describe the phenomenon of desertification, updating is needed. In the latter case, we must have maps of the previous period of vegetation to be able to take possible measures. So far this has not been possible.

Cooperating with the "Map-making Institute" of the Berlin "Technical School", it was possible to develop a method making it

possible to print colored maps of the use of lands (map no. 3) within a few days or a few weeks, according to the numerical classification of the satellite data.

It will thus be possible in future to establish each year planning data with which it will be possible to record and control the extent of the phenomenon of desertification, to facilitate the organization of the measures to be implemented.

5. Evaluation of the Results

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5.1. Exploration of Regional Geology

As we had indicated in Chap. 4.1., it was possible to record quickly and precisely the geology of the Iullemeden basin through satellite pictures.

In the basin itself, we had no difficulties in identifying the laterites extending there in the south and southwest. The extent and limits of the laterites appear with certainty on the satellite pictures. Seeing that a survey of this type may easily be recorded on a pre-existing topographical map, it is possible to know the infrastructural relationships of the laterite deposits with respect to the roads or dams foreseen. This is an interesting fact since laterite is used for building roads and/or dams in the regions of difficult access.

From the hydrogeological point of view, the survey of the photolineations and the extent of the large dunes is important, since they furnish useful data for the exploration of underground waters. Within the dallols, many discharge waterways can be recognized. Their shifts are detected by repeated overflights.

The information we have obtained during the implementation of the studies shows that it is possible to establish quickly geological models in arid countries, on the basis of satellite pictures and control of points of the terrain. When the conditions are favorable, a working capacity of 1 million km² can be achieved in a year and a half.

5.2. Exploration of the Underground Waters

/87

The interpretation of the satellite pictures showed that it may give additional data even when intensive hydrogeological studies were conducted by conventional methods. It is particularly interesting for recording figures of lineations. Indeed the linear structures trace the fractures in the rocks which represent, in the crystalline base, the most important units which are capable of holding water.

The synopsis of the pictures and the possibility of carrying out observations in different regions of the spectrum permit the identification of the linear elements to be carried out more quickly

and with greater precision than would have been possible before the application of this technology.

The indications of water bearing alluvial deposits under the cover of the dunes (Chap. 4.2.2.) had only been identified partly by aerial photos and work on the terrain. There, too, the large field of vision and the possibility of comparing pictures taken at different times (dry season, rainy season) are important factors for the identification of hydrogeological relations.

According to our interpretation, it would be possible to take into consideration all the area located in the south of the Sahara to identify the possibilities offered by the covered fossile alluvial deposits as reservoirs.

5.3. Soils and Use of Lands

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The most important element of the interpretation of pictures to demarcate the pedological units is their usefulness as survey aid.

The semiarid climatic situation of the studied country, and the geology of the region of the Ct in the Niger Republic are good basic principles for the interpretation of the pictures. On the crystalline rock in the southwest of the country, the reduced extent of the units and the semi-humid climate are less suitable for obtaining definitive statements.

The advantage of the interpretation of satellite pictures is due to their large field of vision and the up-to-date nature of their recordings. For planning purposes, it is possible to establish quickly reference documents, for instance in the sector of the use of lands.

The limits of the interpretation of the pictures are given by the resolution of the present satellites which is 79 X 57 m, that is 0.45 ha. In this domain, the satellite pictures are inferior to conventional aerial photographs. It is after all possible to vary according to the needs, the scale of the photographs.

The satellite pictures are used for synoptic surveys visualized on the scales of 1:1 million to 1:250,000. By means of the latter, it is easy to survey units extending over large areas. The areas whose units vary over short distances give a mixed signature on the pictures; it is impossible to achieve on it a more advanced division. The interpretation of the pictures permits the operations on the terrain to be concentrated in limited problematic sectors; it contributes therefore to a more rapid survey of large areas.

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The entire Sahel region is characterized by a very unstable ecological balance. Slight variations may have serious consequences, as shown by the drought of 1969 to 1973. Supervision is therefore a primordial element for recording the gradual changes occurring for the use of lands or vegetation, to cite only these examples. The repeated satellite overflights represent an important condition

of the control, also the obtaining of pictures.

The observations made during this project may be reported in certain cases on the neighboring states of the Niger Republic. To this end, similar climatic conditions must prevail. The multispectral characteristics of the reflectance of certain units vary inside similar climatic domains of the Sahel region within narrow limits, so that the values obtained are valid for surveying large areas. The great advantage of the interpretation of pictures is the up-to-date nature of the maps established. They represent important documents for fast decisions concerning the endangered areas. They are therefore of primordial significance for decisions regarding aid to the developing countries. Possible individual errors of interpretation may be reduced in a great measure by automatic interpretation.

The interpretation of pictures is an important auxiliary method for the evaluation of the resources. For example, in the Niger Republic, it would be possible to estimate the resources of a cotton plantation planned around Madoua and a UNDP development plan in the department of Agades. According to the previous studies, one need not expect any extensive cotton fields west of Madoua, for the morphological conditions would not be suitable. During the U.N. project, the satellite pictures could be used to estimate the irrigated areas in the Air.

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5.4. Conditions for the Establishment of a System of National or Supranational Control

We are now of the opinion that a program of control of the countries of the Sahel and other dry regions is needed. To this end, we will have to establish and implement an effective system for data collection and processing. This system should include the following elements: (Chap. 4.7.3.):

a. Recording Platform: the recording of the terrains to be studied may be implemented by research satellites of the LANDSAT type now operating.

b. Receiving Antenna: the present international development tends to the installation of supraregional collection and processing centers permitting the reception of the data directly above each region of the world. The establishment of this network is only making slow progress. The variations of the orbital parameters of the satellites, the launching of additional satellites and the increasing number of data will lead in the future to the slowing down of data distribution. Furthermore we must expect the daily political situation to have a considerable effect on the recording of data and their distribution and further delays the process of these complex controls.

/91

One alternative:

The German industry (MBB) developed an antenna with control and

recording equipment, which can be transported quickly, by transport aircraft or other vehicles, and can reach any point of the world; it only takes a few hours to get it into operation. It would be possible to collect data from research satellites in certain regions, independently of the regional stations, and distribute the data immediately to the processing plants. The quality of the pictures on the recording site would be controlled by screen, so that first of all the material important to the current studies would be recorded for data processing.

c. Data Processing: it requires considerable deployment of computers, printers and interacting working systems. These plants are used for transforming the crude numerical data of "High Density Digital Tape" (HDDT) into CCT. The latter are then used for the classification and the output of the pictures, as we had previously described.

These plants require investments which are not profitable for a national control program of the regions endangered by the drought; they should be taken over by supranational centers, or entrusted to the control of other institutions.

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One working process was developed by the BGR to achieve a direct classification of the original of the CCT tape and establish from the new tape, models for offset printing of thematic maps in four colors.

d. Printing of the Maps:

The models, one for each color are prepared in such a manner that they can be printed directly by offset color process. The printing is carried out on a rotating offset machine of DIN (German Standards) A 3 format and may be carried out in the Third World country in which the studies are being accomplished. We propose to carry out an experiment over several years in a developing country suffering from a drought; its purpose would be to test under ambiantal conditions the arrangements of a control system in the country subject to desertification. To this end, a receiver antenna must be installed, to organize a flow of data permitting a cartographic survey of specific above-mentioned phenomena without considerable delay.

Application of the Knowledge Acquired to the Organization of Aid

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It is possible to obtain data on the geological and pedological conditions of the subsoil on the basis of the interpretation of the satellite pictures. Although these data provide at first only a limited idea of the shape, the dimensions and the extent of the geological and pedological units, without any information on their quality, simple observations of the terrain, combined with the data supplied by previous studies and interdisciplinary cooperation are sufficient to identify the forms of use of the soils and show the problems raised by the threat of desertification for the natural resources.

The use of pictures for exploring underground waters has also been productive. New data have been acquired on possible water bearing strata, and they may be applied to other countries of the Sahel region, or other arid areas, if the situation is comparable there.

For the countries of the Sahel whose pedological and geological conditions are still poorly known, general surveys should be accomplished according to the needs.

Two important sectors are acknowledged for applying the methods of automatic data processing:

1. the quality of the pictures may be increased by working according to the originals of the recorded tapes. The results of the interpretation are better.

2. for the control of certain phenomena, it is advised to use automatic surveys on computers, for large areas are obtained quickly. It is possible to control terrains in which agricultural and forest use leads to overutilization of the natural factors, which may be the cause of the desertification of entire regions.

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The methods we used during this project, remote detection by satellite, are particularly suitable for establishing quickly reconnaissance maps over large stretches and represents therefore a method of exploration suitable for certain areas and as such, an introduction to the definition of the project.

FEDERAL OFFICE OF GEOLOGICAL SCIENCES AND MINERAL RESOURCES

signed

(Prof. Dr. F. Bender)

Chairman

signed

(Dr. D. Bannert)

Project Director

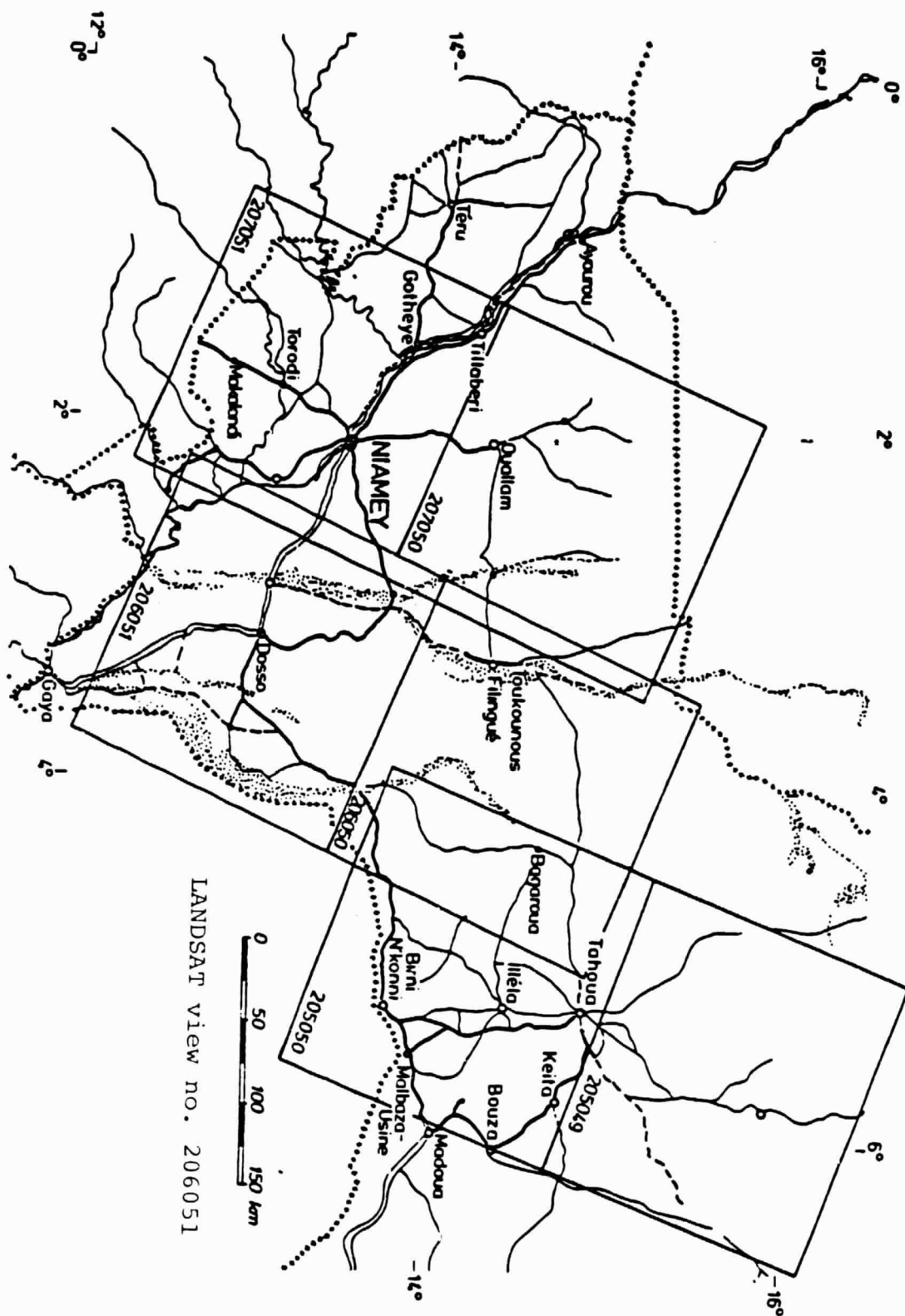


Figure 1. General View of the Niger Republic

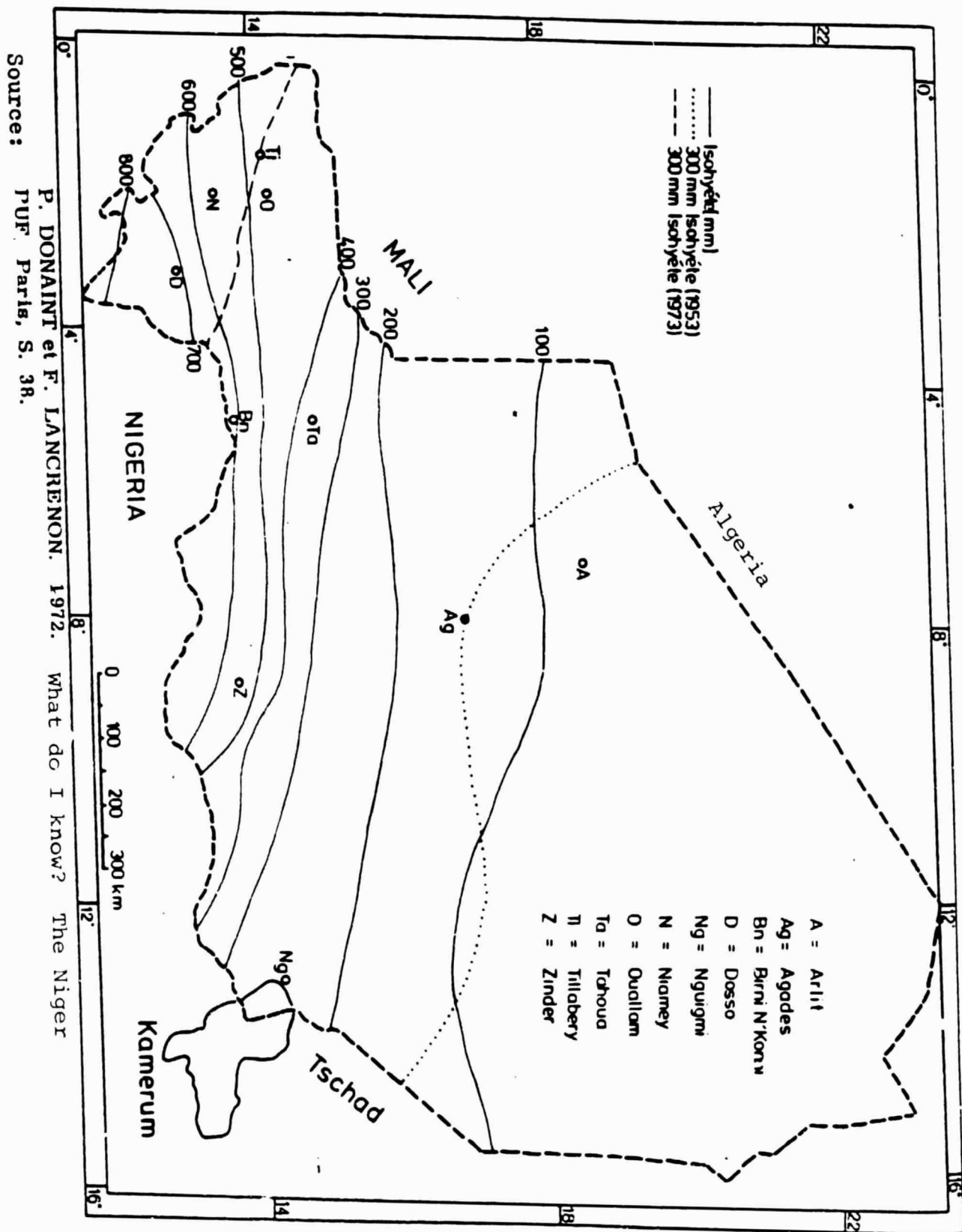
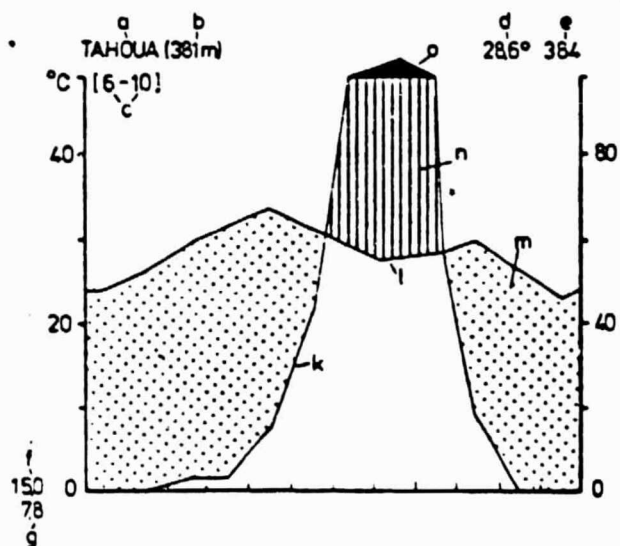
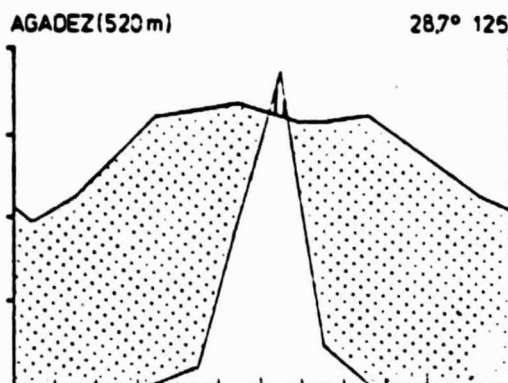
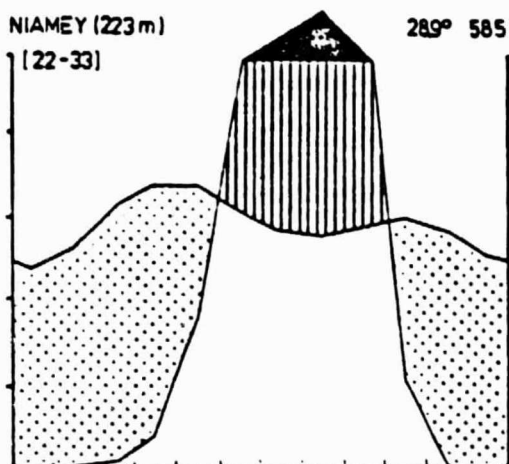


Figure 2. Isohyetes in the Niger Republic



- a - station
- b - altitude
- c - period of observation in years
(the first figure for temperatures, the second for rainfalls)
- d - annual average temperature
- e - average annual rainfalls
- f - daily average minimum of the coldest month
- g - absolute minimum (lowest measured temperature)
- k - curve of average monthly rainfalls
- l - curve of average monthly temperatures
- m - drought (in dash line)
- n - wet season (vertical lines)
- o - average monthly rainfalls exceeding 100 mm (scale reduced to 1/10) black areas

Figure 3. Climatic diagrams of different stations of the Niger Republic

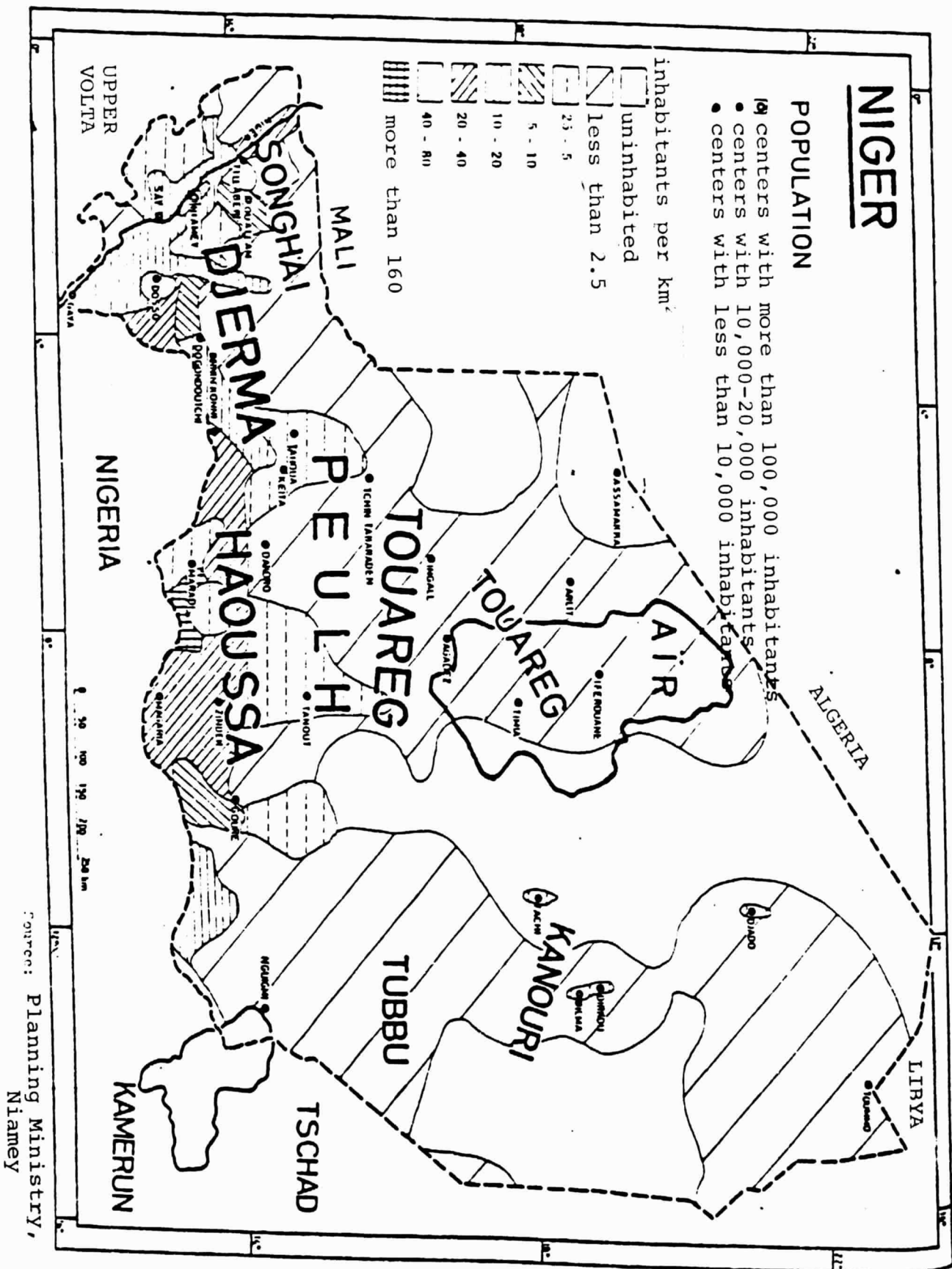


Figure 5. Niger

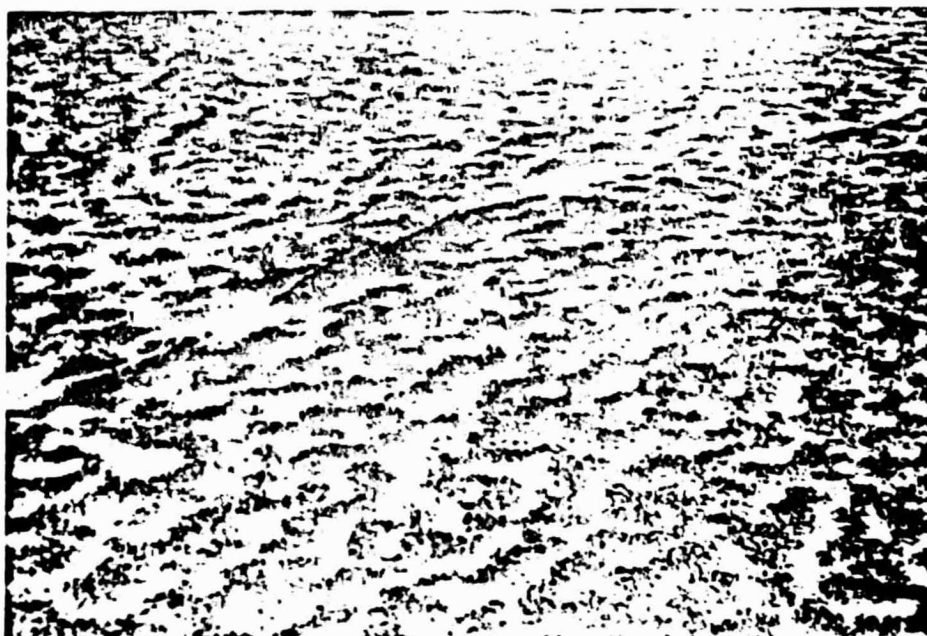


Figure 4. "Striped bush" vegetation northeast of Niamey seen from 400 m altitude in November 1977. Light surfaces = no vegetation, sand; dark surfaces = bush and herbaceous species (Figure in color)

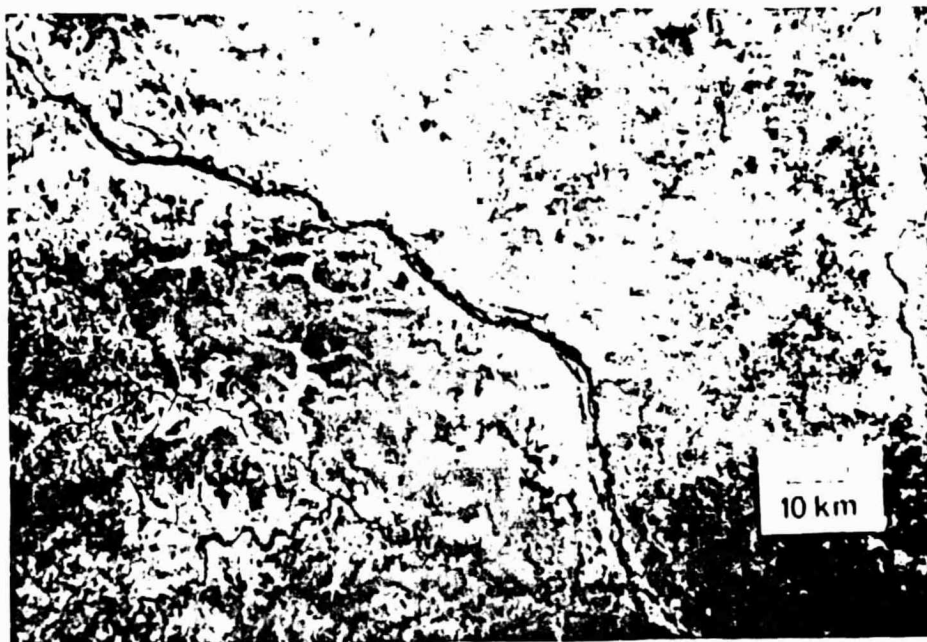


Figure 6. Detail of a satellite picture (ERTS-E-1434-09411) above the Niamey, taken on Sept. 30, 1973. The Niger river appears from Gotheve (top left) to the northwest of Tapoa (bottom right). The red color along the rivers represents the extent of active vegetation; the sandy colored areas are dry farming regions; the reddish-brown areas are lateritic plateaus with "striped bush". North: top of picture. (Figure in color)

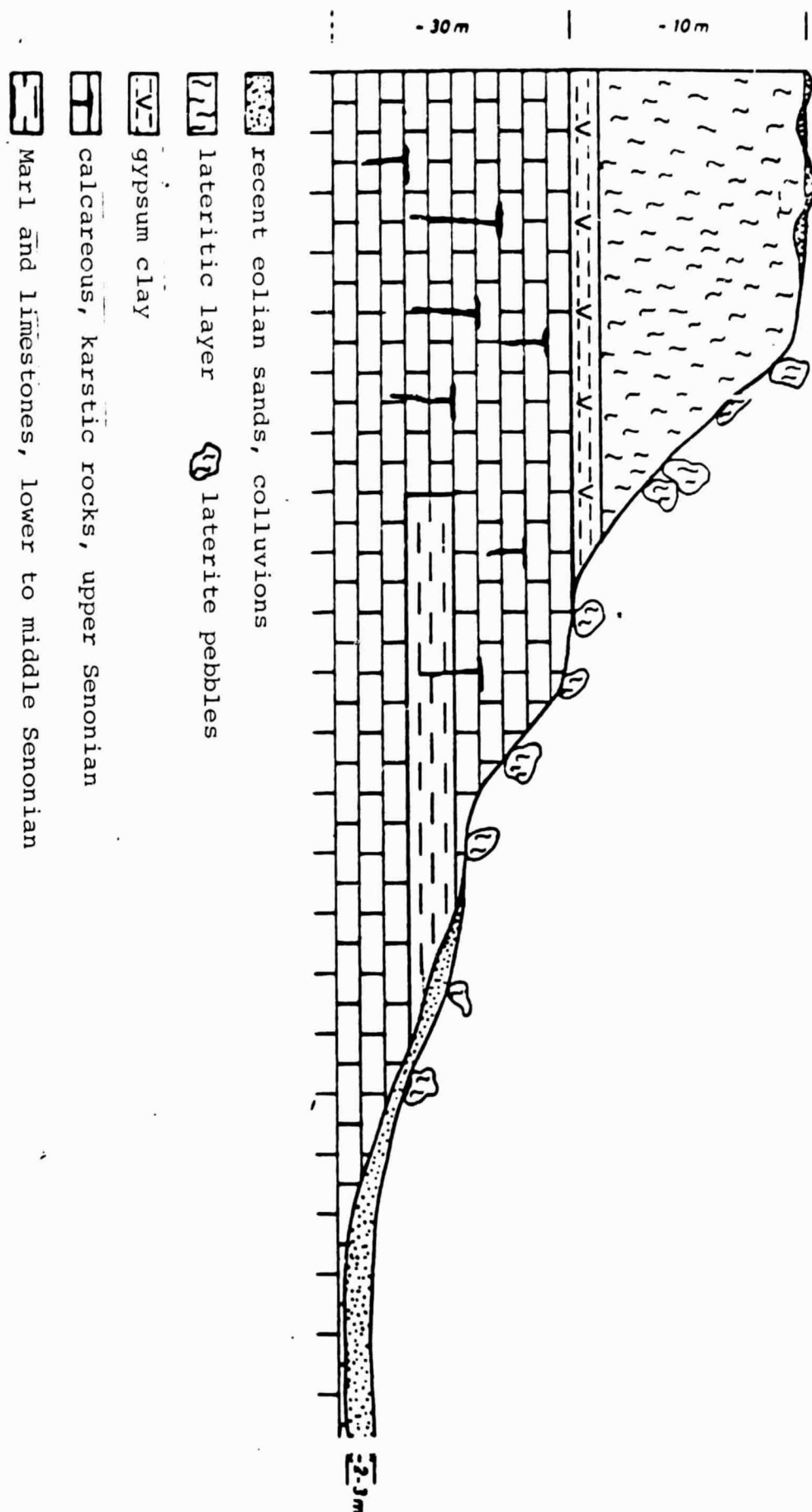


Figure 7. Schematic cross-section of Cretaceous and Tertiary sediments near Keita, southeast of Tahoua, Republic of Niger.



Figure 8. Picture detail (ERTS-E-1271-09374) North Filingue region, Toukounou cattle breeding station (center of picture), 9 November 1972. Light areas: overgrazing areas; dark lines in the Dallol north of Toukounou = vertisols in the waterways; grey-brown area with black border = high northern lateritic plateaus on top (Figure in color)



Figure 9. Boundary between the pastures of the Toukounou cattle breeding station (left) and the surroundings. Photo of March, 1977. (Figure in color)

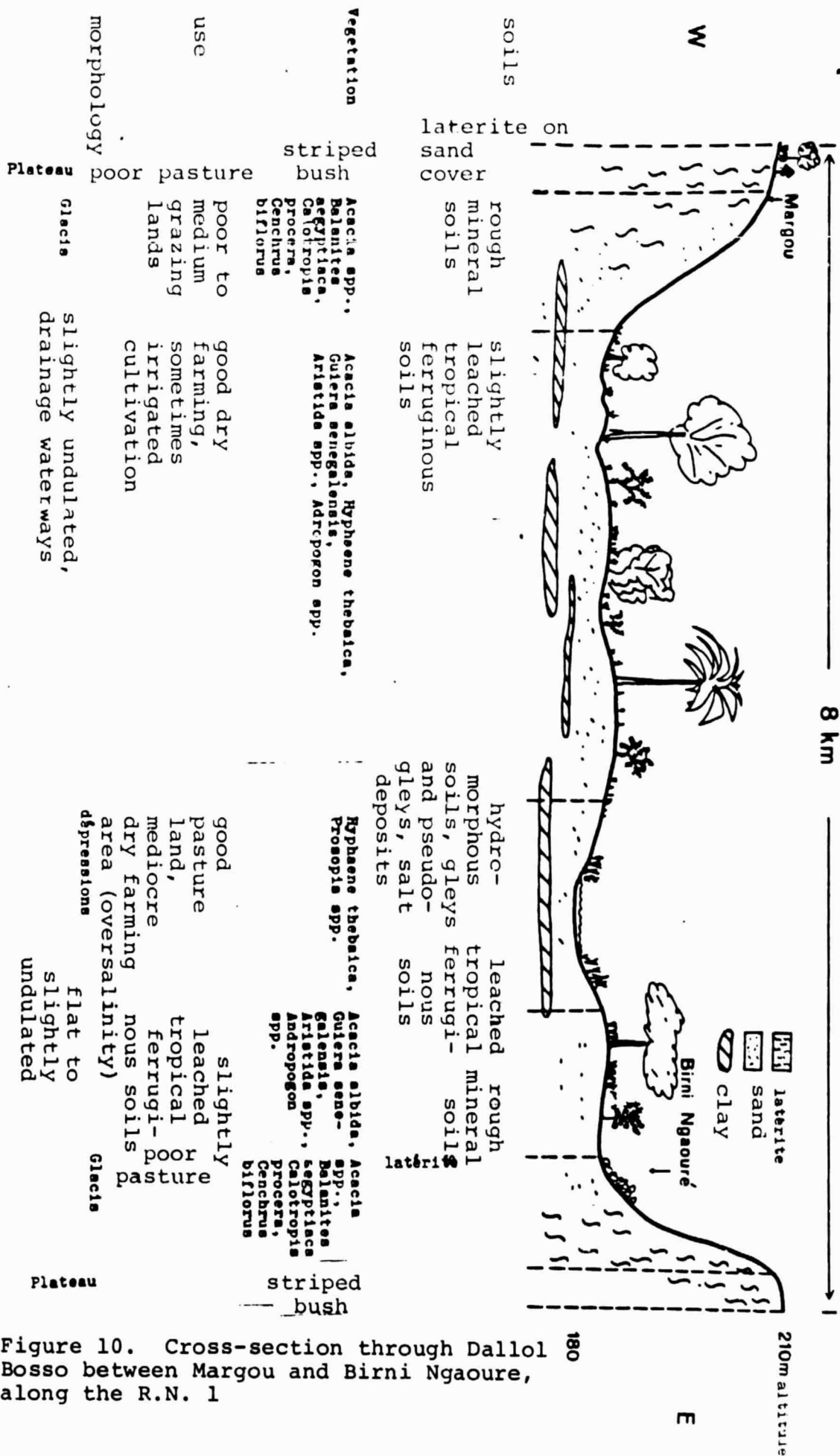


Figure 10. Cross-section through Dallol Bosso between Margou and Birni Ngaoure, along the R.N. 1

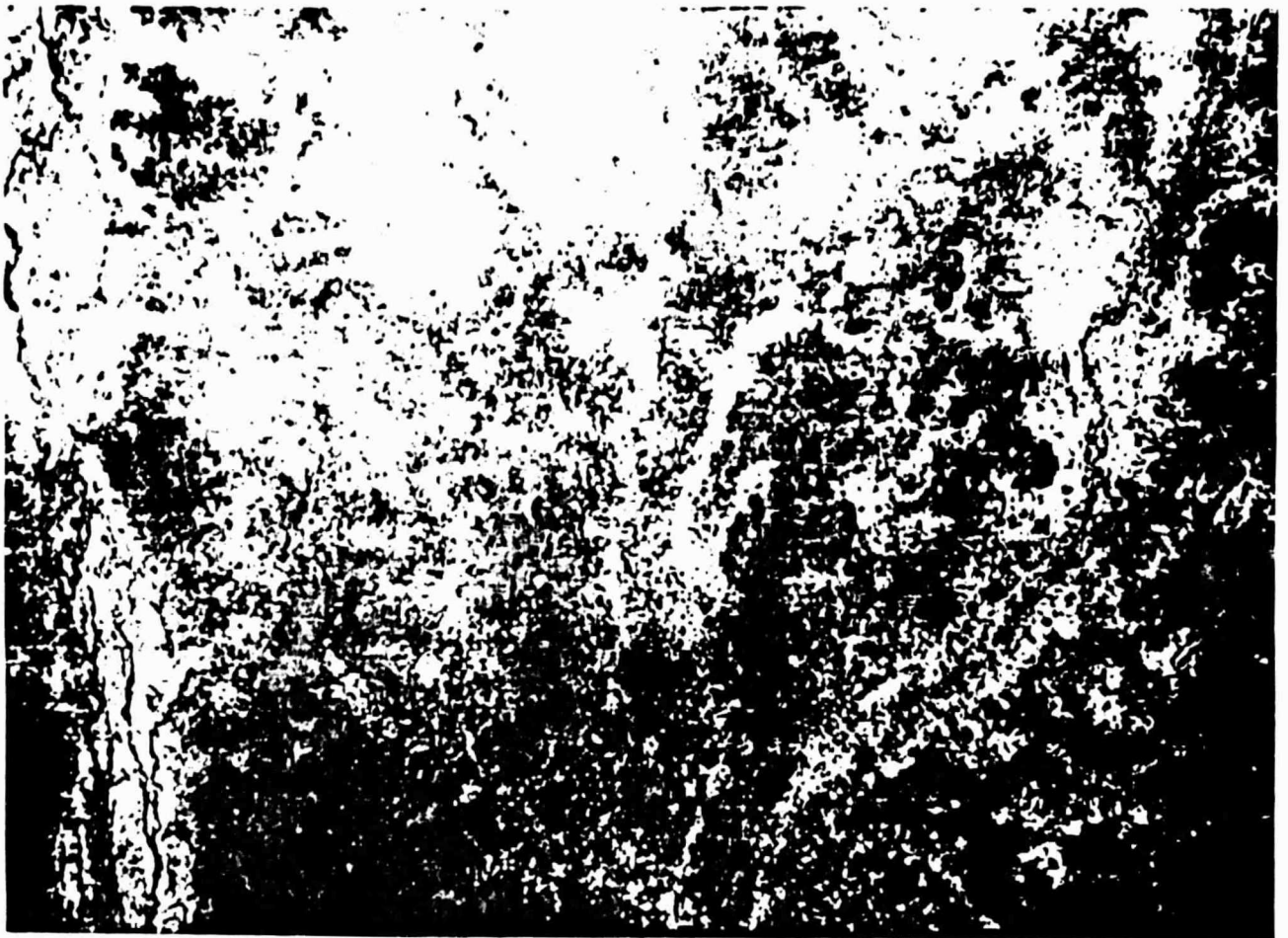


Figure 11. Picture detail (ERTS-E-1433-09353) of the surroundings of Dosso, 29 Sept. 1973; left the Dallol Bosso with humid draining waterways; white points and white areas = prevalence of dry farming; reddish-brown areas = laterite on the spot. North on top. Scale, about 1:750,000 (Figure in color)

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Figure 12. Detail of a satellite picture (ERTS-E-2194-09185) taken on 4 August 1975 southeast of Tahoua. Light blue: water area; light grey and white areas = sands with dry farming and pasture land; red lines: vegetation; black lines: ridges of the laterite layer. North at the top. (Figure in color)



Figure 13. Detail of a satellite picture (ERTS-E-2266-09175) taken on 15 October 1975 southeast of Tahoua (red trapezium top, right) appears clearly; see legend of Figure 12. (Figure in color)

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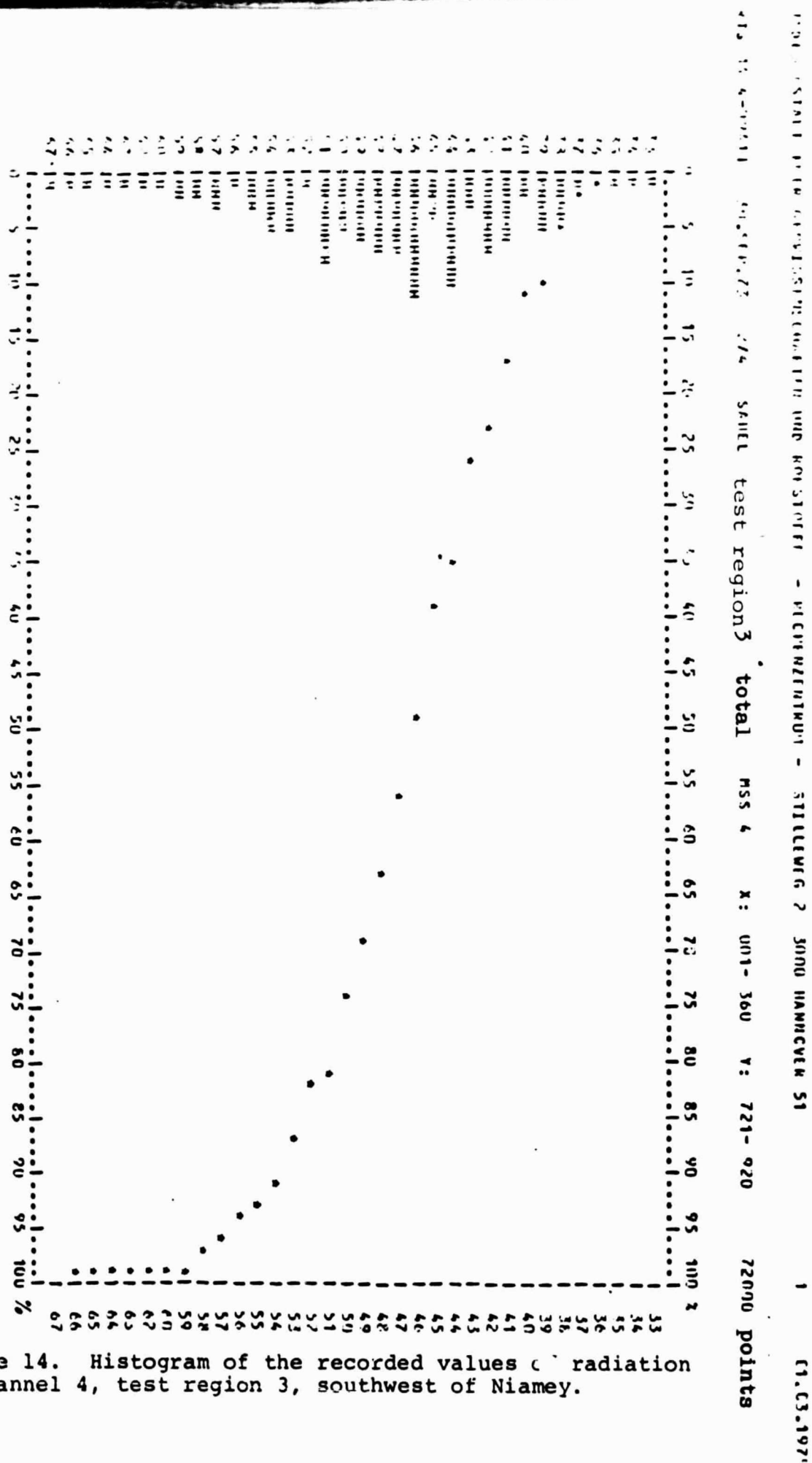


Figure 14. Histogram of the recorded values (radiation) on channel 4, test region 3, southwest of Niamey.

MS 7

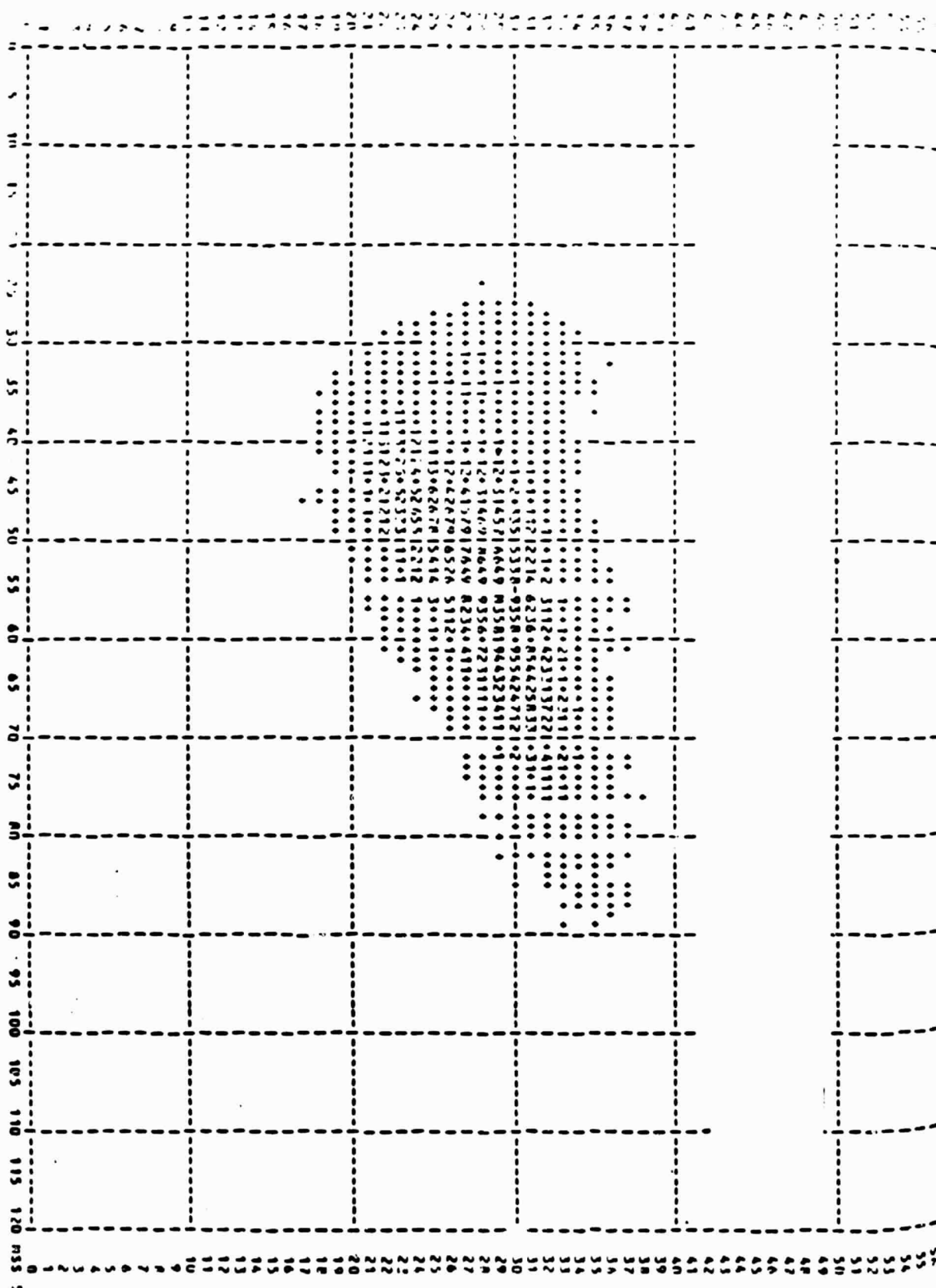


Figure 15. Frequency and distribution of the radiations on channels 5 and 7, test region 3, southwest of Niamey.

Figure 16. Automatic classification of soils SE of Filingue, Republic of Niger

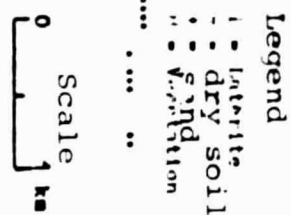


Figure 17. Automatic classification of soils southwest of Niamey, Republic of Niger





Figure 18. Enlargement of channel 7 through automatic and photographic means = southeast of Filingue, 9 November 1972. Light grey areas = pastures on eolian sands; white points on black areas of the upper right portion of the picture: dry farming on dunes; dark or black areas, laterite on the site. Scale: approximately 1:600,000; DFLVR deployment, the north is on top.

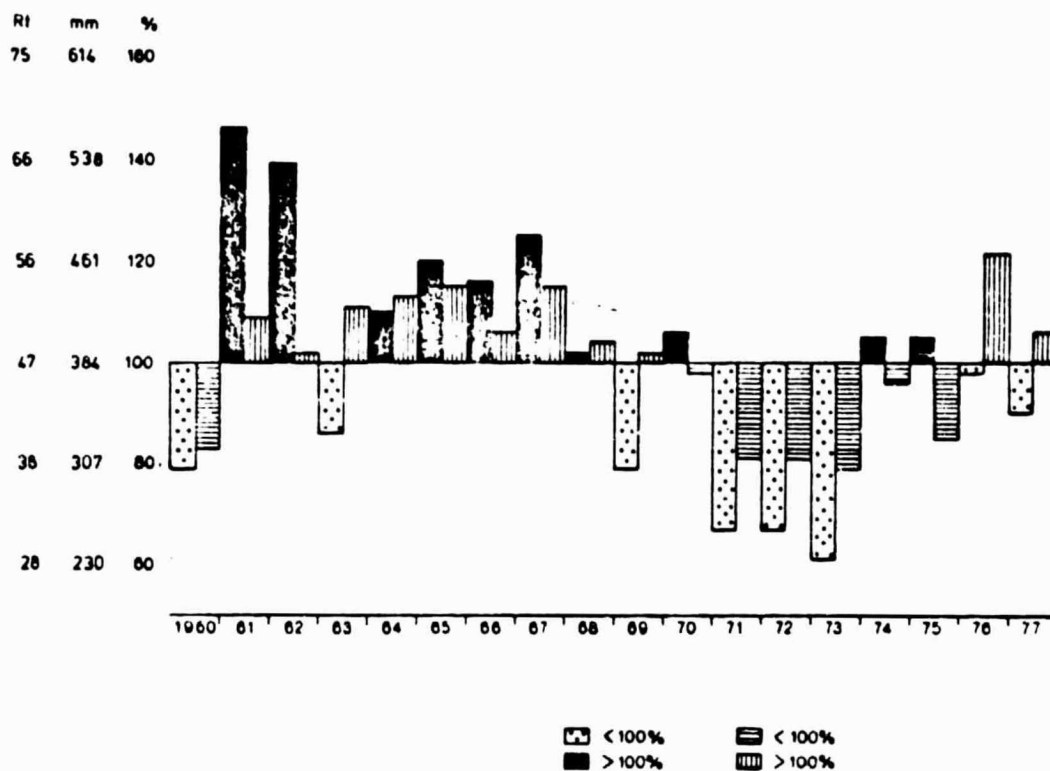
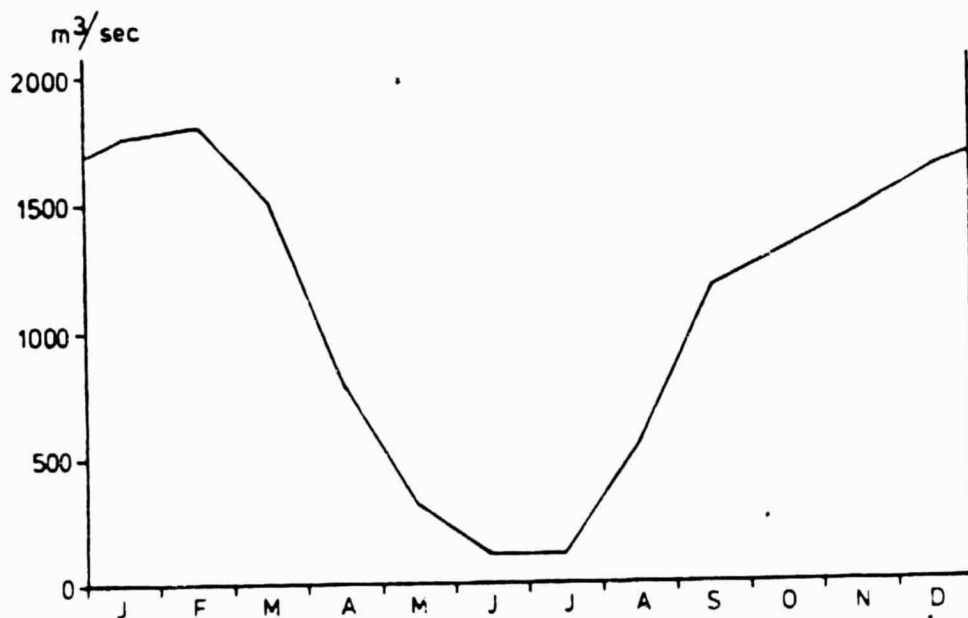


Figure 19. Deviations of annual rainfalls and rainfalls from normal average (18 years) in Tahoua, 100% = 384 mm per year and 47 rainy days per year.



source: WFP, 1977

Figure 20. Rate of flow of the Niger near Niamey.

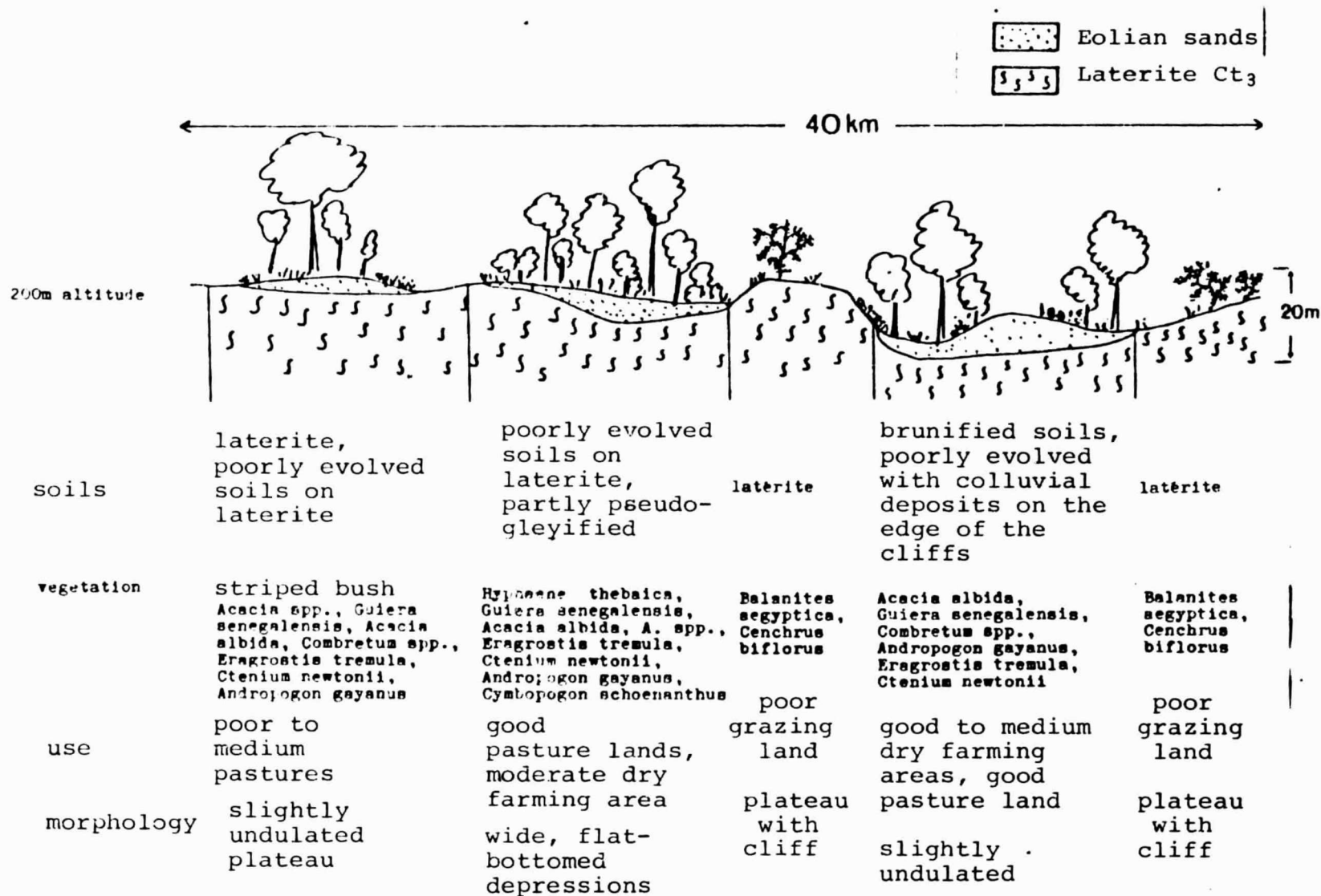


Figure 21. Pedological associations on the Ct terrains northeast of Niamey.

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MAP 1
 REPUBLIC OF NIGER: PEDOLOGICAL INTERPRETATION OF
 LANDSAT PICTURES FROM PREVIOUS PEDOLOGICAL MAPS, 1:1,000,000

Author: W. Kantor

Established on the request of the Federal Ministry of Economic
 Cooperation Project No. 7421373 by the Federal Office of Geological
 Sciences and Mineral Resources

KEY:

- | | |
|-----------------------|---------------------------------|
| 1. Algeria | 8. Roads |
| 2. Libya | 9. Track |
| 3. Upper Volta | 10. Borders |
| 4. Working area | 11. Lakes and ponds |
| 5. Tchad Lake | 12. Waterways, ditches |
| 6. Topographic legend | 13. Wet places |
| 7. Centers | 14. Source: LANDSAT picture no. |

PEDOLOGICAL UNITS	ROCK	MORPHOLOGY	USE (POTENTIAL)
<u>I. Rough Mineral Soils</u>			
Rough non-climatic mineral soils			
Rough erosion mineral soils			
Regosol			
on sands	eolian and river sands (Ct, subrezens)	dry valleys	R:medium to good W:medium
on eolian sands	eolian sands on Ct sand- stone	slightly undulated sandy areas	R:medium to poor W:medium
on sands (saline and alkaline soils)	sandstone, eolian sands	sandy areas with wide depressions locally and with drains	R:nil W:very poor to poor
Rough mineral soils of colluvial origin			
on eolian sands and ferruginous conglomerates	sandy colluvions (Ct, subrezens)	glacis	R:medium to good W:good

MAP 1 (cont.)

PEDOLOGICAL UNITS	ROCK	MORPHOLOGY	USE (POTENTIAL)
<u>II. Poorly Evolved Soils</u>			
Poorly evolved non-climatic soils			
Erosion soils			
Lithic (association with regic soils) and poorly leached ferruginous soils)	sandstone crystalline rock	moderately to highly undulated	R:medium W:medium
Soils of alluvial deposits			
on river sands	eolian and river sands on Ct sandstone	weakly to moderately undulated (river terraces)	R:good W:good
Soils of Eolian origin			
on laterite covered with sand	Eolian sands on Ct	flat to slightly undulated	R:in the depressions W:medium
<u>III. Vertisols</u>			
Vertisols with possible external drainage			
Vertisols with zero external drainage			
Verticulate and holomorphous	alluvial clay	waterways and depressions in dallols	B:rice growing, or nil; hard soil
<u>VI. Isohumic Soils (Steppes)</u>			
Isohumic soils with saturated complex			
Sub-arid brown soils			
Sub-arid red-brown (oligotropic)	Eolian sands (recent Ct)	flat to weakly undulated	R:poor to moderate W:moderate

MAP 1 (cont.)

PEDOLOGICAL UNITS	ROCK	MORPHOLOGY	USE (POTENTIAL)
<u>VII. Brownified Soils</u>			
Brunified soils of tropical countries			
Eutropic tropical brown soils			
Poorly evolved eutropic tropical brown soils	Eolian sands	slightly to moderately undulated sandy area	R:medium to good W:good
<u>IX. Soils with Iron Sesquioxide</u>			
Ferruginous soils			
Slightly leached tropical ferruginous soils			
Pseudogley (locally verticulate and alkaline)	ferruginous soils Eolian and river sands (recent Ct)	waterways in the dallols	R:good to very good B:possible (danger of salinization) W:good
with almost saturated complex, poor in organic substance)	Eolian and river sands (recent Ct)	slightly undulated dallols	R:very good B:good W:good
leached tropical ferruginous soils			
modal (with almost satu- rated complex poor in organic substance)	granites and granodiorites of the crystalline rock	slightly undulated	R:medium to good W:good
hardened locally on ferruginized slabs	ferruginous layer of Ct ¹⁺³	high plateaus covered with slightly undulated Eolian sands	R:non existent W:poor
reorganized over the entire thick- ness of A level (with concretions on ferruginous sandstone)	Eolian sands mixed with debris of ferruginous layer	debris cone and cliffs of the plateau	R:non existent W:non existent
on sands	Eolian sands	wide depressions on the plateau	R:medium to good W:good

MAP 1 (cont.)

PEDOLOGICAL UNITS	ROCK	MORPHOLOGY	USE (POTENTIAL)
Depleted tropical ferruginous soils			
On eolian sands and ferruginous granules	Ct sandstone and Eolian sands	remains of plinthite ridges	R:nil W:poor
on sandstone and limestone	Ct sandstone and CsC cretacean	debris cone and cliffs of the plateau	R:nil W:nil
<u>XI. Hydromorphous Soils</u>			
Mineral or hardly humified hydromorphous soils			
Hardly humiferous hydromorphous soils with gley			
Shallow gley on alluvial deposits of Niger River	alluvial and clay	Niger banks	B:very good to good (subaquatic ricefield) W:very good (compensation grazing)
Hardly humiferous hydromorphous soils with pseudogleys			
soils with perched layer			
poorly drained valleys	alluvial muds and sand	banks	B:moderate to good R:moderate W:good
<u>XII. Sodic Soils</u>			
Sodic soils with degraded structure			
Saline to alkaline soils	alluvial sand and clay	depression with high phreatic layer	R:in some favorable cases W:poor
R: rainy season W: pastures B: irrigation			

MAP 2
REPUBLIC OF THE NIGER, LAND USE ACCORDING TO LANDSAT INTERPRETATION

Scale 1:1,000,000

Author: G. Bake

Established on the request of the Federal Ministry for Economic Cooperation Project No. 7421373 by the Federal Office of Geological Sciences and Mineral Resources

KEY:

- | | |
|----------------|-----------------|
| a. Algeria | c. Lake |
| b. Libya | d. Working area |
| e. Upper Volta | |
1. Irrigated cultivations
 2. Dry farming and irrigated cultivation in the Dallols
 3. Dry farming in the dallols and small valleys, irrigated local cultivations
 4. Dry farming in the dallols
 5. Dry farming; dense distributions of the fields
 6. Dry farming; more sparse distribution of the fields
 7. Dry farming; sporadic distribution of the fields
 8. Controlled pasture lands
 9. Hardly degrade pasture lands
 10. Degraded pastoral territories
 11. Highly degraded pasture land
 - 6/3 Regions of mixed use
 12. Limits of the possibility of identification of dry farming culture
 13. Limitation of the units of use of the soils
 14. Sure
 15. Less sure
 16. Topographic legend
 17. Population centers
 18. Roads
 19. trails
 20. State borders
 21. Waterway

MAP 3

(Legends in English)

MAP 3a
SITUATION OF THE TEST REGIONS CHOSEN FOR AUTOMATIC INTERPRETATION

MAP 4
REPUBLIC OF NIGER: LIPTAKO: HYDROGEOLOGICAL
INTERPRETATION WITH SATELLITE PICTURES

Legend

1. Alluvial deposits
2. Terminal Continental covering the crystalline base
3. Terminal Continental Residues on the crystalline base
4. Crystalline base with alteration layer
5. Crystalline base with dunes
6. Crystalline base
7. Department limits
8. Initial letter of population centers
9. Average rainfall in mm
10. Roads, trails
11. Indications of underground water
12. Locally
13. In layer
14. In points
15. Upper Volta

MAP 5
TERA, UNITS WITH RESERVES OF UNDERGROUND WATER

Key

1. Linear structures (fractures)
2. Fossile alluvial deposits covered with dunes
3. Population centers needing water urgently
4. Western limit of the Terminal Continental with a continuous layer

MAP 6
TILLABERY, UNITS WITH RESERVES OF UNDERGROUND WATER

Legends same as Map 5

MAP 7
GOTHEYE, UNITS WITH RESERVES OF UNDERGROUND WATER

Legends same as Map 5

MAP 8
NIAMEY, UNITS WITH RESERVES OF UNDERGROUND WATER

Legends same as Map 5

MAP 9
SEBBA, UNITS WITH RESERVES OF UNDERGROUND WATER

Legends same as Map 5

MAP 10
DIAPAGA, UNITS WITH RESERVES OF UNDERGROUND WATER

Legends same as Map 5

MAP 11
KIRTACHI, UNITS WITH RESERVES OF UNDERGROUND WATER

Legends same as Map 5